PB84-156421

Airborne Emission Control Technology for the Elemental Phosphorus Industry

Science Applications, Inc., La Jolla, CA

Prepared for

Environmental Protection Agency, Washington, DC

Jan 84

U.S. Department of Commerce
National Technical Information Service
NTIS

PB84-156421

ENERGY SYSTEMS GROUP
SCIENCE APPLICATIONS, INC.

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NATIONAL TECHNICAL
INFORMATION SERVICE
U.S. DEPARTMENT OF COMMERCE
SPRINGFIELD, VA. 22161

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

1. REPORT NO. 68-01-6429	2.	3. RECIPIENT'S ACCESSION NO. PB8 4 156421
4. TITLE AND SUBTITLE Airborne Emission Control Technology for the Elemental Phosphorus Industry		5. REPORT DATE January 1984
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Stula, Belanger, Clary, May, Spaeth, Swenson		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS		10. PROGRAM ELEMENT NO.
		11. CONTRACT/GRANT NO.
12. SPONSORING AGENCY NAME AND ADDRESS U.S. Environmental Protection Agency 401 M Street, S.W. Washington, D.C. 20460		13. TYPE OF REPORT AND PERIOD COVERED
		14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

16. ABSTRACT

Preliminary estimates by the U.S. Environmental Protection Agency (EPA) have indicated the potential for significant radiation doses to individuals near elemental phosphorus plants. During plant operations radionuclides associated with particulates and volatile metallic element radionuclides are released to the atmosphere. Of special interest are polonium-210 and lead-210. The purpose of this work assignment is to apprise EPA of the status of emission of radionuclides to the atmosphere.

This work assignment involves collection of information on emission control technology related to the development of standards under the Clean Air Act. Each work task is designated as a chapter to be incorporated into a Background Information Document for the elemental phosphorus industry. Topics covered include general description of the industry and identification of plant-specific processes and emissions; plant-specific emission control techniques and costs; anticipated industry changes due to modernization, expansion, or process alterations; and definition of a model elemental phosphorus plant representative of those currently in operation. Three levels of control, ranging from minimum to maximum application of emission control techniques, are defined for the model plant along with estimated emissions and equipment costs.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group

18. DISTRIBUTION STATEMENT unlimited	19. SECURITY CLASS *(This Report)* unclassified	21. NO. OF PAGES
	20. SECURITY CLASS *(This page)* unclassified	22. PRICE

EPA Form 2220-1 (Rev. 4-77) PREVIOUS EDITION IS OBSOLETE

AIRBORNE EMISSION CONTROL TECHNOLOGY FOR THE ELEMENTAL PHOSPHORUS INDUSTRY

FINAL REPORT TO THE ENVIRONMENTAL PROTECTION AGENCY

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January 26, 1984

Prepared for U.S. Environmental Protection Agency
Office of Radiation Programs Under Contract
Number 68-01-6429

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Preliminary estimates by the U.S. Environmental Protection Agency (EPA) have indicated the potential for significant radiation doses to individuals near elemental phosphorus plants. During plant operations radionuclides associated with particulates and volatile metallic element radionuclides are released to the atmosphere. Of special interest are polonium-210 and lead-210. The purpose of this work assignment is to apprise EPA of the status of emission controls for elemental phosphorus plants and how they affect the emission of radionuclides to the atmosphere.

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3.1 BACKGROUND

3.1.1 Phosphate Industry

Phosphorus is the twelfth most abundant element in the earth's crust and is widely distributed in both igneous and sedimentary rocks. The commercially minable sources of phosphorus are the phosphate ores known as apatite minerals. Significant deposits of these minerals are known to occur in at least twelve states although in 1980 only seven states were producing phosphate rock (Florida, Tennessee, Alabama, North Carolina, Utah, Montana, and Idaho).

Two extraction methods are used in mining phosphate rock. The method used depends upon the P_2O_5 concentration of the parent material and/or the availability of water. In Florida and North Carolina the technology used is the sluice method. The excavated ore matrix is deposited in a sluice pit, slurried by means of high pressure water, and then conveyed by pipeline to beneficiation facilities for separation of the phosphate rock. In the Western States and Tennessee, the sluicing operation is omitted and the mined ore is shipped by truck or rail car to processing plants.

The United States phosphate rock industry consisted of over 50 working mines in 1979 with a combined production value of greater than one billion dollars (57 million short tons marketable production) [1]. Depending on the product orientation, marketable phosphate rock is sold either as an end product or to processing plants that convert the rock into phosphoric acid, fertilizers, elemental phosphorus, detergents, animal feeds, or other phosphorus-containing chemicals. Of the total marketable phosphate rock in 1980, approximately 10 percent was used in the production of elemental phosphorus [2]. In 1979, the phosphoric acid production from phosphate rock amounted to over 10 million short tons while the production of elemental phosphorus was an estimated 460,000 short tons [1].

Phosphoric acid is produced by "wet-process" phosphoric acid plants while elemental phosphorus is produced by "dry-process" electric furnace plants. An illustrated example of the supply and demand for material of the phosphate industry is presented in Figure 3-1 [3]. Although the percentages are based on 1975 industry data, they serve to illustrate the relative importance of the distribution pathways of the phosphate rock industry. During 1975, the U. S. phosphate rock industry produced 48.8 million short tons of marketable material [1]. The mass of phosphate material mined is such that it makes phosphate mining the fifth largest mining industry in the United States.

The major production of phosphate ore in the United States occurs in Florida. The Florida phosphate industry is the principal mineral industry in that state and accounts for over 90 percent of the United States phosphate production. The size of the Florida phosphate mining industry, however, does not coincide proportionally with the source of raw material used in the elemental phosphorus industry. Data gathered for this investigation indicates that in 1982 less than 10 percent of the elemental phosphorus produced was from Florida phosphate. Approximately 30 percent was produced in Tennessee using Tennessee phosphate, while the remainder was produced in Idaho and Montana using Idaho phosphate.

3.1.2 Product Description and Uses

The major products of the elemental phosphorus industry are elemental phosphorus and the by-products associated with its production. Elemental phosphorus is primarily used in the manufacture of high-grade phosphoric acid, which serves as a feed stock for the production of high-grade chemicals and food products. Elemental phosphorus is an important chemical in a number of consumer items such as cleaning compounds, pharmaceuticals, soft drinks, and a variety of food items. Detergent production accounts for an estimated 40 percent of the elemental phosphorus, food and beverages for 15 percent, and metal treating, especially surface preparation of steel for automobiles, for 10 percent [4].

The major by-product of elemental phosphorus production is calcium silicate slag. Some known or potential uses of the slag are given in Table 3-1 [5,6,7]. Slag is normally produced at rates of 8 to 9 tons per ton of phosphorus recovered from an electric furnace [7]. The quantity of

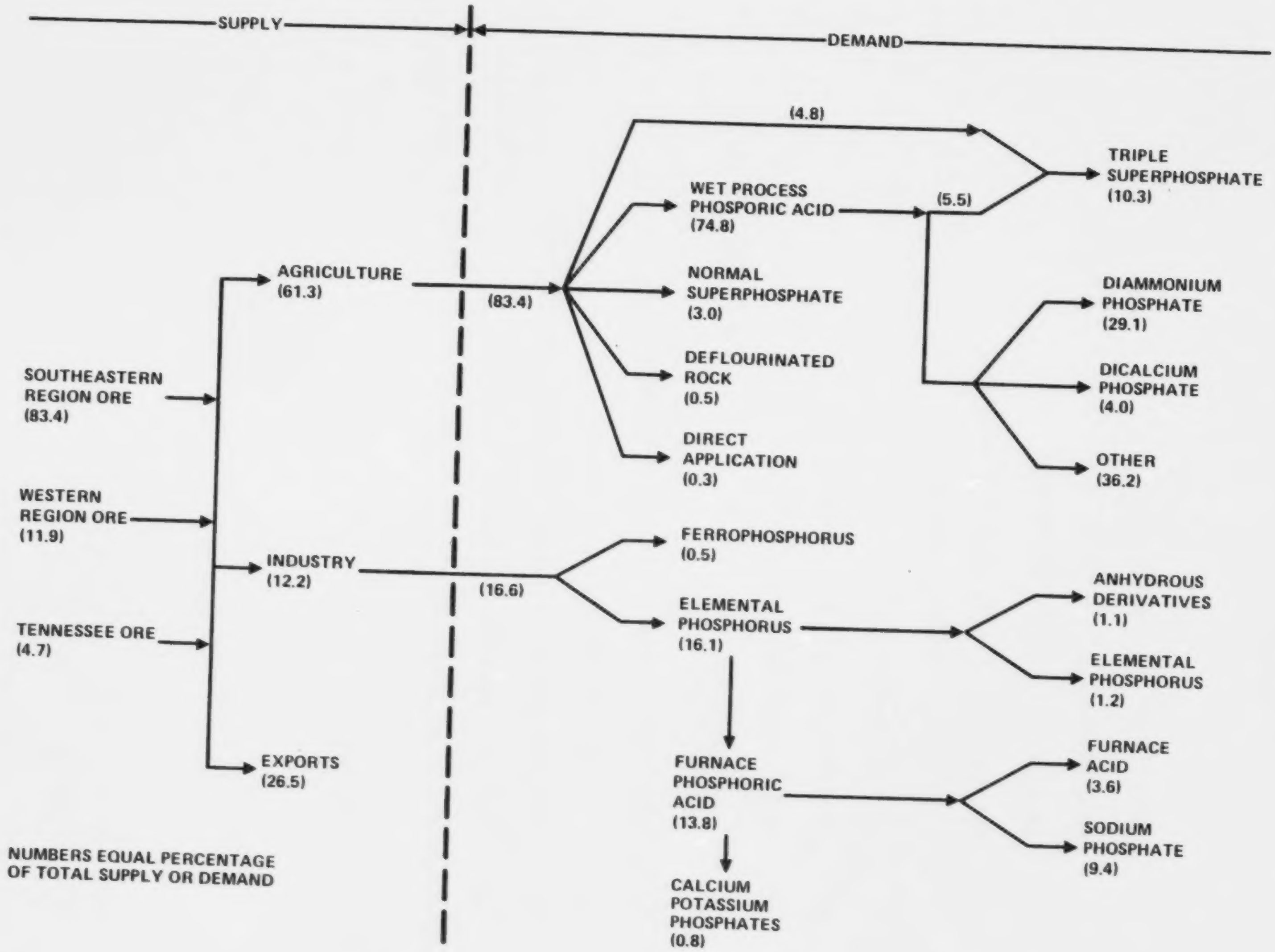

SUPPLY
DEMAND
SOUTHEASTERN REGION ORE (83.4)
WESTERN REGION ORE (11.9)
TENNESSEE ORE (4.7)
AGRICULTURE (61.3)
INDUSTRY (12.2)
EXPORTS (26.5)
(83.4)
(16.6)
(4.8)
WET PROCESS PHOSPORIC ACID (74.8)
NORMAL SUPERPHOSPHATE (3.0)
DEFLOURINATED ROCK (0.5)
DIRECT APPLICATION (0.3)
(5.5)
TRIPLE SUPERPHOSPHATE (10.3)
DIAMMONIUM PHOSPHATE (29.1)
DICALCIUM PHOSPHATE (4.0)
OTHER (36.2)
FERROPHOSPHORUS (0.5)
ELEMENTAL PHOSPHORUS (16.1)
ANHYDROUS DERIVATIVES (1.1)
ELEMENTAL PHOSPHORUS (1.2)
FURNACE PHOSPHORIC ACID (13.8)
FURNACE ACID (3.6)
SODIUM PHOSPHATE (9.4)
CALCIUM POTASSIUM PHOSPHATES (0.8)
NUMBERS EQUAL PERCENTAGE OF TOTAL SUPPLY OR DEMAND

Figure 3-1. Phosphate Industry - Supply and Demand in 1975 [3].

Table 3-1. Potential and Actual Uses of Elemental Phosphorus By-product Slag [5,6,7].

- Neutralizer for acidic soils
- Road ballast
- Manufacture of Portland cement
- Manufacture of slag concrete blocks
- Slag wool as thermal insulation
- Ceramic bodies and glazes
- Railroad ballast and roadbeds
- Septic tank drainage fields
- Commercial and utility use for roadways, substations, and soil stabilization
- Municipal sewage plants (filter beds)
- Parking lot and driveway paving
- Private use for driveways, patios, and drainage
- Built-up roofing aggregate

slag produced varies with the grade of the phosphate ore and the SiO_2 to CaO ratio of the feed to the electric furnace. The quantity of phosphorus in the slag varies with raw material composition and the method of furnace operation. Table 3-2 shows the sales distribution patterns for different grades of slag from the Florida elemental phosphorus industry [5]. Although the annual total slag production listed in Table 3-2 is considerably higher than that expected for the Florida elemental phosphorus industry in 1982, the table serves to illustrate the distribution patterns for different grades of slag.

The second major byproduct of elemental phosphorus production is ferrophosphorus. Slag and ferrophosphorus are generally sold separately but operations do exist in which the slag and ferrophosphorus are sold as a mixture. The ferrophosphorus that is sold enters a number of secondary markets such as the manufacture of special types of steel, casting alloys, paint pigments, and the petroleum industry. In some cases, the vanadium and chromium content in ferrophosphorus is high enough to make their extraction economically feasible.

Other significant by-products are processed dust removed from the furnace offgas stream and furnace offgas condenser exhaust. Dust collected from the offgas has a potential market as a fertilizer, while condenser exhaust gas, which is mainly carbon monoxide, is utilized by the phosphorus plant as a fuel.

3.1.3 Industry Outlook

In the 1970s, the production of elemental phosphorus declined because of changes in the U.S. economic condition and the environmental concern that resulted in reduced use of phosphate-based detergents. As a result of the reduced demand, the U. S. phosphorus industry has contracted its manufacturing base. Two elemental phosphorus plants have closed since 1980, but are still functional and could be reopened.

Currently, there are six operating plants which are located in Tennessee (three), Idaho (two), and Montana (one). These six plants plus the two inactive but functional plants located in Florida are the focus of this study. Based on data gathered, these eight functional plants represent an estimated cumulative production design capacity of approximately 550,000

Table 3-2. Sales Distribution (1978 Short Tons) of Florida Furnace Slag by End Use Category [5].

Slag Grades	Highway Paving	Railroad Ballast Road Beds	Septic Tanks	Roadway Substations And Soil Stabilization	Municipal Sewage Treatment Plants	Parking Lot And Driveway Paving	Private Use Patios Etc.	Roofing	Concrete Product Use	Total Tonnage By Grades
Drainfield 1 1/2" to 3/4"	-	778.57	51,827.55	13,495.38	22,631.79	626.88	2,880.19	-	-	92,240.36
#11 1" to 1/2"	4,087.71	-	547.23	9,968.43	4,598.48	471.24	1,524.80	-	-	21,197.89
#12 Nominal 7/8"	24,547.43	-	42,360.67	10,476.12	-	703.55	2,061.89	-	1,426.73	81,576.39
#15 Nominal 3/8"	23,090.48	-	-	610.30	-	880.07	360.19	24,016.56	46.76	49,004.36
#16 3/8" to 1/8"	65,592.98	-	-	561.42	2,531.48	1,727.79	1,464.93	6,178.38	213.63	78,270.61
Fines -10 Mesh	11,384.82	-	-	468.33	-	210.50	479.11	-	261.72	12,804.48
Totals	128,703.42	778.57	94,735.45	35,579.98	29,761.75	4,620.03	8,771.11	30,194.94	1,948.84	335,094.09
% of Total	38.4	0.2	28.3	10.6	8.9	1.4	2.6	9.0	0.6	

short tons per year. However, during 1982, the six operating plants were only operating at about 72 percent of their design capacity.

Data also indicate that while the production of phosphate rock is increasing (up to 57 million short tons in 1979 from 48.8 million short tons in 1975 [1]), elemental phosphorus production is decreasing. The 1982 estimated elemental phosphorus production was only 381,000 short tons compared with the 1979 production of 460,000 tons [1].

Thus, even though the industry has plenty of available phosphate rock and a continued demand for pure phosphorus, the probability of growth in the elemental phosphorus industry is not high. Economics, population growth, and environmental concerns are working against a major increase in the major consumption areas of elemental phosphorus: detergents, food additives, and metal treating.

Rising electrical costs may also impact the industry. The electrothermal processing of phosphate rock is essentially a nonelectrolytic heating process that produces elemental phosphorus by chemically reducing phosphate rock. The most common configuration of the electric furnace incorporates three carbon electrodes up to approximately 1 m in diameter. These large electrodes are three-phase units operating at 200 to 300 V, 5000 to 50,000 amps, and a power use of 50,000 kW or more [7]. In 1978, electricity represented 34 percent of the production cost of phosphorus [8]. In 1982, electrical costs for a typical furnace ranged from $215 to $580 per short ton of phosphorus produced (i.e., approximately 13,000 kWh per short ton). In addition, approximately 1000 kWh per short ton of phosphorus produced may be required by the auxiliary plant power. Thus, escalating electrical costs may cause phosphorus prices to increase enough to significantly reduce elemental phosphorus use.

A third factor affecting the industry's future involves technological developments. Currently, an estimated 85 percent of the elemental phosphorus produced is used in the manufacture of high-grade phosphoric acid, which is relatively unchanged from the 87 percent used in this way in 1974 [4,9]. In the manufacture of phosphorus-containing fertilizer, a wet process is utilized that produces phosphoric acid from dry phosphate rock. If the technology for purifying the phosphoric acid derived by the wet process improves significantly, this could reduce the demand for high-grade phosphoric acid from elemental phosphorus. This ultimately could result in market loss for the elemental phosphorus industry.

3.1.4 Radionuclide Distribution

Phosphate formations contain concentrations of uranium decay series radionuclides substantially above normal background. Uranium-238 is a primordial radionuclide that heads a series of heavy radioactive atoms (Figure 3-2). If a deposit is sufficiently old and has not been subjected to physical or chemical separation processes, the radionuclides present should be in a state of radioactive equilibrium, wherein the rate of decay of each radionuclide is very nearly equal to that of the parent uranium-238 [10]. In some conditions, this equilibrium can be altered for the series radionuclides beyond radium-226. This is because the daughter of radium-226 is gaseous radon-222, which can diffuse out of shallow, porous materials and be transported some distance before decaying to its particulate daughter, polonium-218.

The mining and processing of phosphate deposits may enhance human exposure to radiation, an example of what has been designated "technologically enhanced natural radiation," or TENR [11]. Radiation exposure pathways associated with the phosphate industry include direct exposure, inhalation, and ingestion. Some direct exposure to gamma radiation could occur because external gamma radiation levels near phosphate ore stockpiles are significantly higher than normal background. The primary radiological hazards, however, involve inhalation or ingestion of radionuclides.

Radionuclides may become airborne, and thus available for inhalation, by at least three distinct mechanisms: (1) the mechanical suspension of radioactive particulates from phosphate ore materials; (2) the emanation of radon-222 from radium-containing materials; and (3) the atmospheric discharge of particulate or volatilized radioactive material through stacks and other release points in the phosphorus production process.

There are also at least three distinct pathways by which ingestion may result: (1) the contamination of potable groundwater supplies by phosphate mining or related activities; (2) consumption of food crops contaminated by radionuclide deposition or plant uptake; and (3) consumption of meat or milk products from animals that have consumed contaminated feed materials.

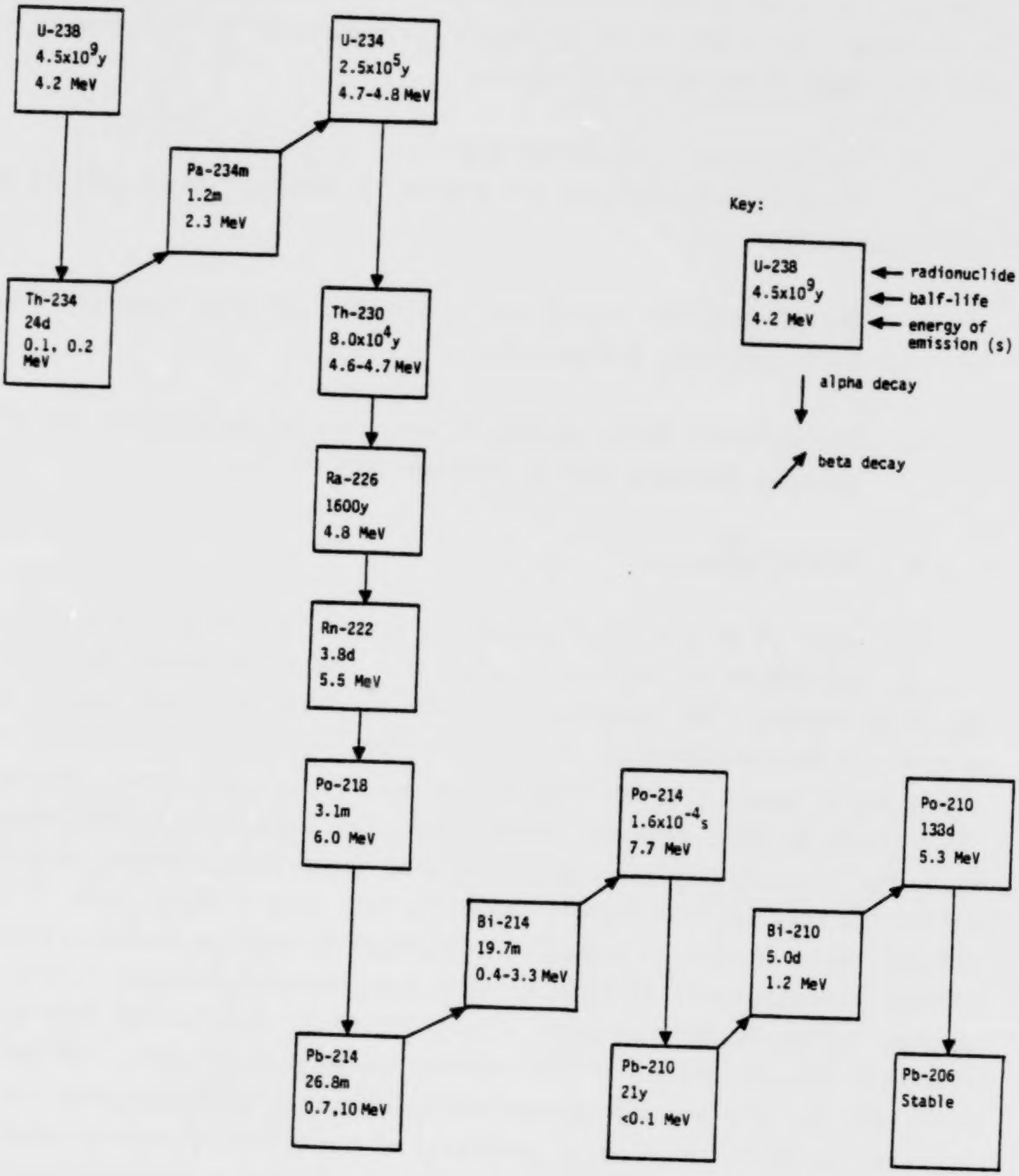

U-238
4.5x10^9 y
4.2 MeV
Th-234
24d
0.1, 0.2 MeV
Pa-234m
1.2m
2.3 MeV
U-234
2.5x10^5 y
4.7-4.8 MeV
Th-230
8.0x10^4 y
4.6-4.7 MeV
Ra-226
1600y
4.8 MeV
Rn-222
3.8d
5.5 MeV
Po-218
3.1m
6.0 MeV
Pb-214
26.8m
0.7,10 MeV
Bi-214
19.7m
0.4-3.3 MeV
Po-214
1.6x10^-4 s
7.7 MeV
Pb-210
21y
<0.1 MeV
Bi-210
5.0d
1.2 MeV
Po-210
133d
5.3 MeV
Pb-206
Stable
Key:
U-238
4.5x10^9 y
4.2 MeV
radionuclide
half-life
energy of emission (s)
alpha decay
beta decay

Figure 3-2. The Uranium Decay Series.

This report is concerned primarily with the airborne radioactivity exposure pathways, and discussions of emissions will be limited to these aspects. The distribution of radionuclides in the feed materials, products, by-products, and wastes of the elemental phopshorus production process is also discussed in the following section.

3.1.4.1 Radionuclides in Phosphate Ores

Phosphate ore deposits are located in three principal regions of the United States:

- The southeastern region (mainly Florida, but also South Carolina, North Carolina, and Georgia).
- The northern Rocky Mountain region of eastern Idaho, western Wyoming, northern Utah and southwestern Montana.
- Middle Tennessee

Most of this country's marketable phosphate rock is produced in Florida, but most of the ore used in elemental phosphorus production is from the other regions. The phosphate ores from the three principal regions are distinct in their radiological characteristics. Generally, ores from the southeastern region have the highest radionuclide concentrations, followed respectively by those from the western region and those from middle Tennessee. The radioactivity content of phosphate rocks from different deposits within the same general region, however, may vary widely. Most of the natural radioactivity present is represented by uranium series radionuclides, although some phosphate rocks also contain elevated levels of thorium and its daughter products. Table 3-3 gives radionuclide concentration data for phosphate rocks of various geographic origins. The table indicates that the uranium series radionuclides in phosphate ores are in equilibrium. Also, the primary processes of ore beneficiation to produce marketable phosphate rock do not appear to significantly alter this equilibrium. The washing of ore, which takes place in the process feed preparation stage, has been shown to slightly increase the concentration of uranium

Table 3-3. Radionuclide Concentrations in Phosphate Rocks of Various Origins.

Origin	Type of Material	No. Samples	Radionuclide Concentration (pCi/g)			Remarks
			U-238	Ra-226	Th-232	
Florida	Pebble	11	69	73	1.5	Data are from Ref. [13]; concentration data are median values and are converted to pCi/g from reported units of ng/kg or mg/kg
		4	73	74	1.2	
		14	49	53	1.4	
		12	42	43	1.9	
	Soft phosphate	7	34	31	2.1	
	Miscellaneous phosphate	9	25	21	1.9	
North Florida	Mining land matrix	4	NS(1)	8.6	NS	Data are from Ref. [14]; concentration data are mean values and are reported on dry weight basis
	Pebble	1	NS	26	NS	
	Rock concentrate	4	NS	17	NS	
Central Florida	Mining land matrix	6	NS	38	NS	
	Pebble	13	NS	57	NS	
	Rock concentrate	12	NS	35	NS	
North Florida	Mining land matrix	NS	7.6	8.6	NS	Data are from Ref [15]; concentration data are mean values of composite samples
Central Florida	Mining land matrix	NS	20	18	NS	
Florida	Marketable phosphate rock	NS	41	42	0.5	Data are from Ref. [12]
Tennessee	Brown rock	17	3.6	4	0.7	Data are from Ref. [13] and are median values converted to pCi/g from reported units of ng/kg or mg/kg
		8	4.3	4	0.6	
		3	3.3	4	0.7	
Tennessee	Blue rock	3	5.3	7	0.3	
	White rock	4	3.3	5	0.2	
	Phosphatic limestone	3	2.6	3	0.2	
South Carolina	Phosphate	11	132	133	2.1	
North Carolina	Phosphate	3	25	18	1.0	
Arkansas	Phosphate	13	9.9	11	1.4	
Oklahoma	Phosphate	5	8.3	10	0.9	
Montana	Phosphate	10	38	41	0.8	
Idaho	Phosphate	5	50	49	0.9	
Wyoming	Phosphate	4	60	62	1.3	
Utah	Phosphate	9	42	50	0.8	

(1) NS = Not specified

series radionuclides, indicating that the uranium and its daughters are more closely associated with the phosphate ore than with the barren fines [12].

3.1.4.2 Products and Waste Materials

Radionuclide concentrations in elemental phosphorus are very low because of numerous plant production isolation and purification process steps. Elevated concentrations of uranium series radionuclides, however, are found in the slag, the furnace offgas precipitator dust, and to a much lesser extent, the ferrophosphorous. In an activity balance of the nonvolatile radionuclides entering the elemental phosphorus production process, virtually all the output activity can be accounted for in the slag.

3.1.4.3 Process Emissions

The elemental phosphorus thermal production process results in the release of fugitive dust and particulate emissions containing uranium series radionuclides. In addition, two long-lived radon daughters, lead-210 and polonium-210, have boiling points low enough to be vaporized by the thermal process, resulting in the release of lead-210 and polonium-210 fumes to the atmosphere. In general, the air pollution control equipment in phosphorus plants is installed to reduce particulate and fluoride emissions. While such equipment is also effective for reducing emissions of radioactive particulate material, it is much less effective at removing radionuclides present as fumes or vapors. Polonium-210, for example, is volatilized during phosphate ore calcining, and significant quantities can be released through particulate emission control equipment during calcining. Airborne emissions from specific plants are discussed in Section 3.3, while a general description of emission control technology is presented in Section 3.2.5.

3.2 GENERAL DESCRIPTION OF ELEMENTAL PHOSPHORUS INDUSTRY

3.2.1 Plants

Table 3-4 lists each plant examined in this study, its location, its startup date, and its design capacity. Also given are population density, general climate conditions, and the percentage of surrounding area dedicated to farmland. The population densities are for the counties in

Table 3-4. U. S. Elemental Phosphorus Plants Location and General Site Description.

Company - Location	Furnace Startup Date	Design Capacity ($\times10^3$ short tons/yr)	Population Density (per km^2)	General Climate	Environs Dedicated To Farmland (Percent)
FMC Corporation Pocatello, ID	1949	135	18	Semiarid	55
Monsanto Company Soda Springs, ID	1952	105	3	Semiarid	65
Stauffer Chemical Silver Bow, MT	1952	42	20	Semiarid	29
Stauffer Chemical Mt. Pleasant, TN	1937	45	32	Moderate Rainfall	75
Occidental Chemical Columbia, TN	1953	50	32	Moderate Rainfall	75
Monsanto Company Columbia, TN	1937	133	32	Moderate Rainfall	75
Mobil Chemical Pierce, FL (Inactive)	1952	20	68	Moderate Rainfall	67
Stauffer Chemical Tarpon Springs, FL (Inactive)	1947	23	1073	Moderate Rainfall	9

which the plants are located, and the area dedicated to farmland is based on the 1974 Census of Agriculture [16,17].

3.2.2 Basic Process

Elemental phosphorus is produced by a thermal process that uses silica as a fluxing agent for the calcium present in phosphate feed ore. Phosphate is reacted with silica and coke to form elemental phosphorus (P_4), carbon monoxide (CO), and calcium silicate slag. In addition, byproduct ferrophosphorus (FeP) is formed from the reaction of elemental phosphorus with coke and iron oxide. Simplified equations for the process are:

$$(1)\ 4\ \underset{\text{(ore)}}{Ca_5F(PO_4)_3} + 18\ SiO_2 + 30\ C \rightarrow 18\ \underset{\text{(slag)}}{CaO \cdot SiO_2 \cdot 1/9\ CaF_2} + 30\ CO\uparrow + 3P_4\uparrow$$

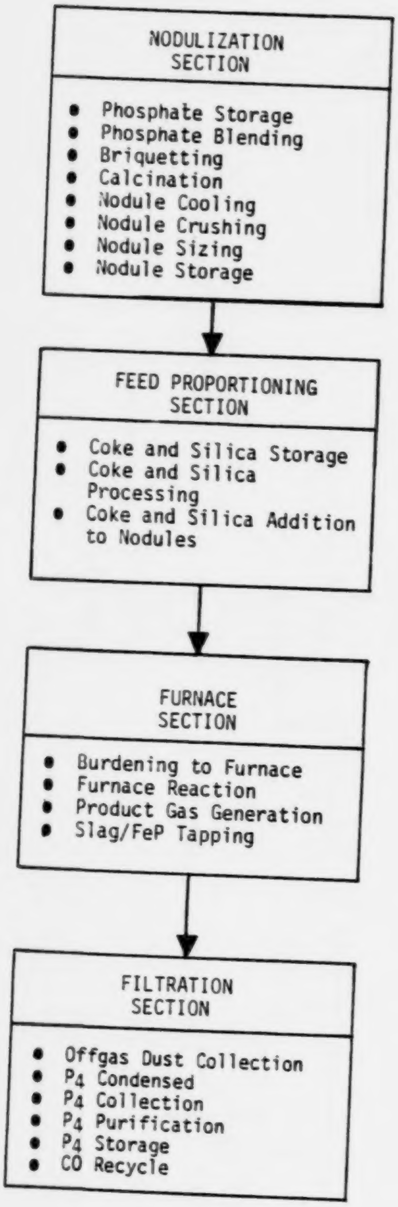
$$(2)\ 2\ P_2O_5 + 10\ C \rightarrow 10\ CO\uparrow + P_4\uparrow \quad \text{(intermediate reaction)}$$

$$(3)\ 2\ Fe_2O_3 + 6C + P_4 \rightarrow 4\ FeP + 6\ CO\uparrow$$

A step-by-step diagram of the elemental phosphorus production process is shown in Figure 3-3, and a simplified general process flow diagram is shown in Figure 3-4. The major process steps shown in Figure 3-3 are described below.

- Step 1 -- Phosphate Nodulization. The phosphate feed ore is shipped to the plant and generally stockpiled before use. Various material handling systems are used that blend the phosphate feed ore to achieve required feed specifications. Recycled process fines and dust are typically blended with this phosphate feed ore.

  The blended feed material is sent to a rotary kiln where the material is heated to its incipient melting point (~1300°C) and the tumbling action agglomerates the feed into the desired larger nodular form. In some instances, feed material is briquetted before being sent to calciners that volatize organic material and water, increase P_2O_5 content, and heat-harden the briquettes so


NODULIZATION SECTION
Phosphate Storage
Phosphate Blending
Briquetting
Calcination
Nodule Cooling
Nodule Crushing
Nodule Sizing
Nodule Storage
FEED PROPORTIONING SECTION
Coke and Silica Storage
Coke and Silica Processing
Coke and Silica Addition to Nodules
FURNACE SECTION
Burdening to Furnace
Furnace Reaction
Product Gas Generation
Slag/FeP Tapping
FILTRATION SECTION
Offgas Dust Collection
P4 Condensed
P4 Collection
P4 Purification
P4 Storage
CO Recycle

Step 1

PHOSPHATE FEED NODULIZATION

a. Phosphate is received and stored
b. Nodule/briquette feed is prepared
c. Nodules are formed and calcined
d. Nodules are cooled, crushed and sized
e. Nodules are stored

Step 2

PREPARATION OF FURNACE FEED

a. Coke and silica are received, stored and processed
b. Coke and silica are mixed in proportion with nodules
c. Furnace feed is conveyed to burden bins

Step 3

ELEMENTAL PHOSPHORUS PRODUCTION

a. Furnace feed is fed to furnace
b. Phosphorus is produced
c. CO/P_4 offgas is collected
d. Slag/FeP is tapped and processed or stored

Step 4

ELEMENTAL PHOSPHORUS RECOVERY

a. Dust is removed from furnace offgas
b. P_4 is condensed and collected
c. P_4 is purified and stored
d. CO is recycled to plant or flared

Figure 3-3. Elemental Phosphorus Production Process.

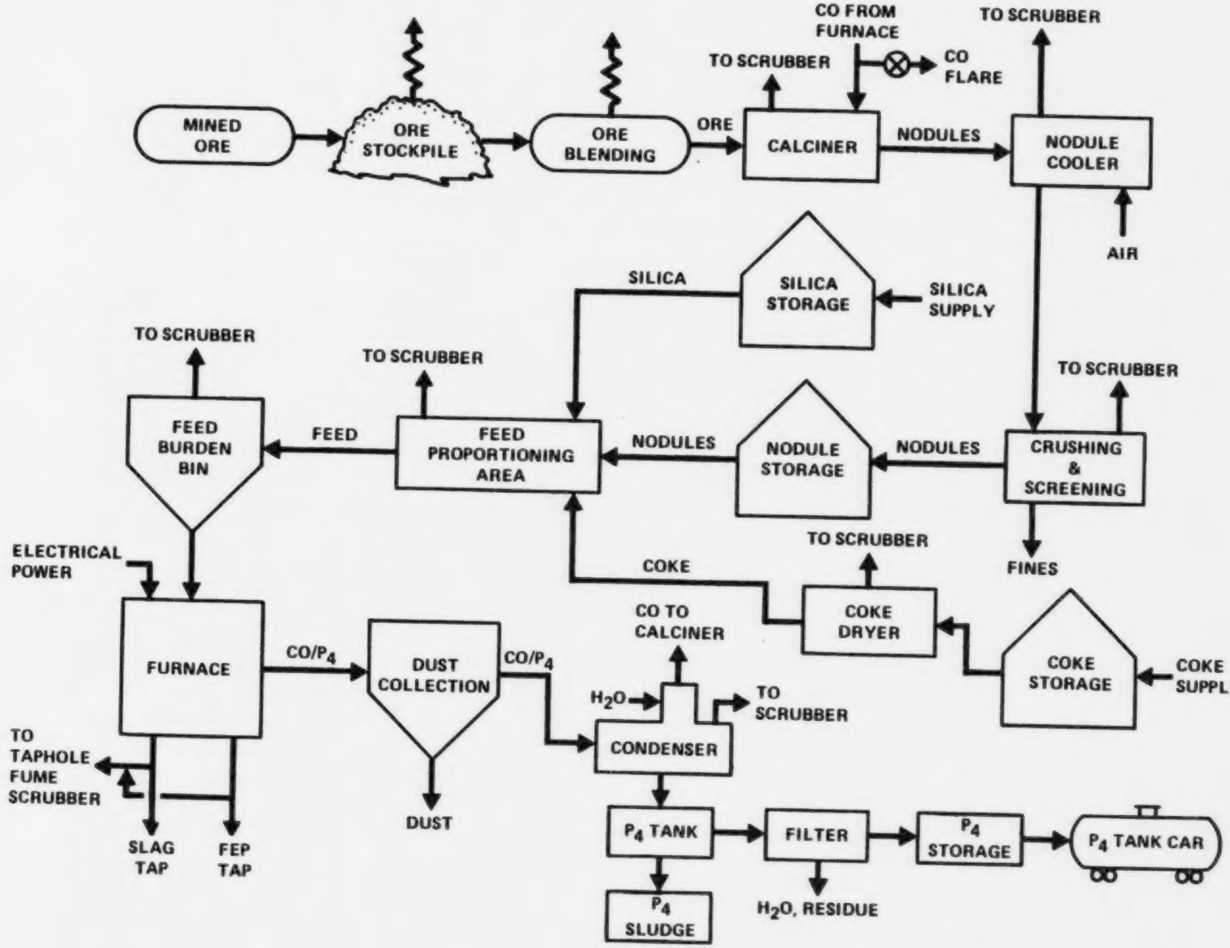

MINED ORE
ORE STOCKPILE
ORE BLENDING
ORE
TO SCRUBBER
CO FROM FURNACE
CO FLARE
CALCINER
NODULES
TO SCRUBBER
NODULE COOLER
AIR
SILICA
SILICA STORAGE
SILICA SUPPLY
TO SCRUBBER
TO SCRUBBER
TO SCRUBBER
FEED BURDEN BIN
FEED
FEED PROPORTIONING AREA
NODULES
NODULE STORAGE
NODULES
CRUSHING & SCREENING
FINES
TO SCRUBBER
COKE
COKE DRYER
COKE STORAGE
COKE SUPPLY
ELECTRICAL POWER
FURNACE
CO/P_4
DUST COLLECTION
CO/P_4
CO TO CALCINER
H_2O
TO SCRUBBER
CONDENSER
TO TAPHOLE FUME SCRUBBER
SLAG TAP
FEP TAP
DUST
P_4 TANK
FILTER
P_4 STORAGE
P_4 TANK CAR
P_4 SLUDGE
H_2O, RESIDUE

Figure 3-4. General Elemental Phosphorus Plant Process Flow.

they will withstand further processing steps without disintegrating. The nodules or briquettes are then air-cooled and passed through crushing and sizing operations (approximately 1.5-2.5 cm diameter) before being sent to storage or to the feed proportioning step of the flowsheet.

- Step 2 -- Furnace Feed Proportioning. The nodulized or briquetted phosphate feed material is sent to a proportioning area where it is mixed with sized coke and silica to obtain the required weight proportion of furnace feed (burden). A proper ratio of SiO_2 to CaO is required to form slag with the necessary flow properties to facilitate removal from the furnace. Coke is added as a carbon source to reduce the intermediate reaction product P_2O_5 to elemental phosphorus. This proportioned furnace feed burden is conveyed to the furnace burden bins.

- Step 3 -- Furnace Operation. The electric furnace is a large chamber lined with carbon blocks in the lower section. Three consumable carbon electrodes extend through the roof to conduct the electric current. An electric arc is formed between the electrodes and the furnace lining. The burden material is gravity fed to the top of the furnace from where it progresses downward until it is heated and eventually melts (at approximately 1400-1800°C) in the intense heat of the electric arc. At the heat source, the maximum temperature can reach 4400°C. At 1400-1800°C, silica becomes a strong acid that reacts with the calcium phosphate to yield a calcium silicate slag and P_2O_5. The P_2O_5 in turn reacts with the carbon in the coke and is reduced to CO and P_4.

The elemental phosphorus is driven off as a vapor in the CO off-gas stream. The slag and ferrophosphorus continually collect in the bottom of the furnace in molten layers with the denser ferrophosphorus situated below the slag. Periodically, these molten byproducts are separately tapped. Slag is tapped approximately once each hour and ferrophosphorus up to several times each day.

- Step 4 -- Phosphorus Filtration. The furnace product gases are typically treated for dust removal in a mechanical collector or electrostatic precipitator. The cleaned gases are then sent to water spray condensers where the gases are cooled and the phosphorus is condensed to a liquid. Most of the phosphorus-free CO is recycled to fuel the nodulization process. The remaining CO is recycled to other plant operations or exhausted through flare stacks. The condensed phosphorus is collected under water, purified by filtering, and then pumped to underwater storage.

3.2.3 Major Process Variations

The process just described is typical of most elemental phosphorus facilities. However, several major process variations exist among the eight plants examined in this study.

The phosphate ores mined throughout the country possess varying chemical and physical characteristics (e.g., P_2O_5 content and particle size). As a result, each existing plant has its own methods for handling and processing this material before calcination. The various methods used include:

- Crushing, screening, and briquetting
- Drying, screening, and briquetting
- Washing and wet concentrate blending
- Dry blending with other recycle materials

After initial handling and processing, the phosphate feed material is calcined in one of several types of calcining operations. Briquetted feed is typically baked in a moving grate calciner. Generally, phosphate feed is not briquetted but is nodulized during calcination in rotary kilns.

The feed proportioning areas of the various plants generally consist of similar operations with a few exceptions. Most plants dry, crush, and screen the coke before mixing it with the phosphate feed nodules.

Some plants use significantly different processing and handling procedures. Silica generally undergoes little or no processing other than drying after reaching the plant.

The major process variations in the furnace operation consist of the methods and procedures used to remove and handle slag and ferrophosphorus by-products. Using long probes for flow control, workmen allow molten slag and ferrophosphorus to flow out of the furnace through tapholes. The slag is usually cooled by water spray and then reclaimed for subsequent processing and sale or stockpiling. In some instances, a handling method is used in which a large truck-mounted ladle collects the molten slag, which is then transported to and dumped onto a slag pile where it solidifies. Ferrophosphorus is typically drawn off into chill molds where it is cooled and then processed (crushing and screening) before sale. At some plants, the ferrophosphorus may be removed and sold without processing or may be allowed to flow into trenches with the slag and be subsequently separated after solidification.

Major process variations in the phosphorus filtration section of the flowsheet include the methods and procedures used to remove and process entrained dust in the furnace product offgas stream. Dust is normally removed with a mechanical collector or electrostatic precipitator and then either processed for sale or sent to disposal. Processing methods used consist of fluid bed drying of slurried dust or the use of a burning chamber to treat dry dust. The cleaned furnace offgas stream is normally routed to a spray condenser where phosphorus is separated from the CO. An alternative of this process is the use of an air-cooled condenser. Condensed phosphorus is collected and then sent to various types of filtering operations to remove impurities. In some instances, phosphorus sludge is treated in roasters or evaporators to increase recovery of phosphorus.

3.2.4 Process Materials

3.2.4.1 Feed Materials

The three main feed materials used in the production of elemental phosphorus are phosphate ore, coke, and silica. Depending on the location of the phosphate ore source, the phosphate ore may vary significantly both chemically and physically. These differences necessitate different handling and treating methods before calcination. Phosphate ore types and materials currently used include:

- Pebble rock (>1 mm)
- Sand (<1 mm)
- Shale (small pellets)
- Rock concentrate
- Washed sand tailings

With few exceptions, P_2O_5 content of phosphate ore used in elemental phosphorus furnaces ranges from 22 to 30 percent. Ore compositions on a plant-specific basis are provided in Section 3.3

If the ore material contains excess moisture or impurities, procedures including drying or washing may be desired. Oversized ore may be crushed and screened before calcination. In most plants, this processed ore is blended with other recycled materials, including process fines and dust, reclaimed fines from ponds, and residue from roasting of nodule fines and phosphorus product sludge. Depending on the physical characteristics of the blended feed material, it may be calcined with or without briquetting. Briquetting is currently performed in two of the eight domestic plants and may include the use of phosphoric acid as a binding material. When phosphate feed is calcined in rotary kilns or moving grate calciners, the moisture, sulfur, carbon dioxide, organic matter, and much of the fluorine are volatilized. Nodules are typically more porous than uncalcined feeds and result in markedly superior furnace operation as well as decreased power requirements.

In the feed proportioning area of each plant, coke and silica are blended with the phosphate nodules according to furnace feed specifications. The physical characteristics of coke used vary from plant to plant. Most coke used contains approximately 85 to 90 percent carbon (dry weight basis), ranges in size from 0.9 to 2.5 cm, and is either produced locally or purchased. In addition, most plants use a coke dryer. Silica is usually mined locally in either pebble or sand form and contains approximately 96 to 98 percent SiO_2.

Electricity may also be considered as a feed material. Electrical energy requirements vary with the composition of the feed charge, increasingly linearly as the P_2O_5 content of the phosphate plus silica decreases. In addition, electricity needs increase as the Fe_2O_3 content in the feed charge increases since the ferrophosphorus formation requires energy. Most plants require 12,000-13,500 kWh for each short ton of elemental phosphorus produced.

To achieve satisfactory furnace performance, the feed charge must meet certain physical and chemical specifications. Variations in the size and proportion of coke used in the charge affect the electrical conductivity of the charge, which in normal operation affects the position of the carbon electrodes for a given power load and voltage. Small-sized coke or a small proportion of coke causes the electrodes to penetrate deeper into the charge, which can potentially damage the furnace. When there is insufficient coke present, carbon from the electrodes can be consumed. Typical electrode consumption is 23 to 27 kg per short ton of elemental phosphorus produced. The size of the coke also affects the uniformity of the feed charge. Since the density of the coke is much less than that of the phosphate and silica, serious segregation could occur during handling if the size is not properly controlled.

A large excess of coke can cause the furnace electrodes to assume positions high in the furnace. This would result in a low temperature at the furnace bottom and make tapping of slag and ferrophosphorus more difficult. As a result of experience gained from the operation of furnaces with different proportions of coke, the practice of adding a little more than the quantity theoretically required to reduce the P_2O_5 and Fe_2O_3 was adopted. The excess carbon required is calculated from the total carbon content of the coke used. The excess coke charged in the feed usually amounts to 3 to 4 percent.

The silica charged to the furnace should contain a high percentage of SiO_2 and very little Fe_2O_3 and CaO. Experience has shown that silica rock should be approximately the same size as the phosphate nodules to prevent its segregation from the charge. As the silica content of the phosphate feed increases, less silica must be added to the feed charge. The ratio of SiO_2 to CaO in the furnace slag dictates the amount of silica to be fed to the process.

Other materials required on a plant-wide basis include lime and various fuels used to supply process heat. Lime is typically used to neutralize scrubber water or other plant process water. Most plants mainly use recycled furnace offgas CO to fuel the kilns (calciners), dryers, and other processes requiring process heat. When required, auxiliary fuels such as coal, oil and natural gas are also used.

3.2.4.2 Product Materials

The primary product of the furnace operation is gaseous elemental phosphorus, which exits the furnace at approximately 400°C along with the by-product CO. The phosphorus is subsequently condensed and separated from the CO stream before undergoing further filtration. Typical phosphorus product purity is >99.9 weight percent. At some plants, dust removed from the furnace offgas stream is processed and sold for use as fertilizer. This material typically contains significant amounts of P_2O_5 (17-30 percent), CaO (7-16 percent), SiO_2 (11-20 percent), and other metals such as Zn (5-8 percent) and K (5-20 percent). The by-product CO stream (approximately 90-95 percent CO) is either recycled to the plant to be used as fuel or is flared to the atmosphere.

The other significant by-products resulting from elemental phosphorus production are calcium silicate slag and ferrophosphorus, which are tapped from the furnace as molten liquids. The typical composition of furnace slags is given in Table 3-5. Analyses of slags have shown that P_2O_5 content increases as the proportion of the coke in the feed charge decreases. Similarly, the P_2O_5 content in the slag increases as the proportion of SiO_2 in the feed charge decreases. Operating experience has indicated that a ratio of SiO_2 to CaO of approximately 0.8 to 0.9 in the feed charge is preferred. The maximum volatilization of phosphorus from charges of phosphate, coke, and silica heated to temperatures of 1300 to 1500°C occurs at a SiO_2 to CaO weight ratio of about 0.86. At ratios below 0.8, slag tapping is more difficult because of a somewhat more viscous slag material. Slag composition is constantly analyzed so the silica added to the furnace feed may be controlled to yield the proper ratio of SiO_2 to CaO in the slag. More than 95 percent of all CaO, SiO_2, and Al_2O_3 charged to

Table 3-5. Typical Composition of Western Slag and Ferrophosphorus(1).

Product	Component	Weight Percent
Slag	SiO_2	39-45
	CaO	40-48
	Al_2O_3	5-7
	Fe_2O_3	0.2-0.6
	P_2O_5	0.5-3.0
	F	2.7-3.2
Ferrophosphorus	Fe	56-60
	P	24.5-27.8
	Si	0.5-4.5
	V	3.9-5.5
	Cr	3.6-4.6

(1) FMC plant data (Pocatello, Idaho).

the furnace is usually found in the slag. Phosphates containing relatively large percentages of Al_2O_3 (4-7 percent) require smaller additions of SiO_2 to the furnace charge.

The Fe_2O_3 charged to the furnace is reduced to form elemental iron, and the iron combines with phosphorus to form the alloy-like metallic compound ferrophosphorus. The specific gravity of the solid material ranges from 5 to 6, depending on the phosphorus content. Since ferrophosphorus is considerably denser than slag, it collects in the bottom of the furnace. The alloys of iron and phosphorus are divided into five classes as follows [18]:

(1) Alloys that contain 0 to 1.7 weight percent phosphorus and consist of solid solutions of Fe_3P in iron.

(2) Alloys that contain 1.7 to 10.2 weight percent phosphorus and form solid solutions of Fe_3P and iron.

(3) Alloys that contain 10.2 to 15.5 weight percent phosphorus and consist of the eutectic and Fe_3P (Fe_3P melting point is 1060°C).

(4) Alloys that contain 15.6 to 21.6 weight percent phosphorus and consist of Fe_3P and Fe_2P.

(5) Alloys that contain more than 21.6 weight percent phosphorus and contain Fe_2P and another phosphide richer in phosphorus.

Most of the ferrophosphorus made in the phosphorus furnaces contains from 22 to 30 percent phosphorus; therefore, the usual plant material is considered to be in class 5 above and to consist of the compounds Fe_2P and FeP. The plant material also contains 0.1 to 6.0 percent silicon and small amounts of other metals, such as vanadium, chromium, manganese, and calcium. Phosphates in the western United States contain significant amounts of vanadium and chromium that concentrate in the FeP. Ferrophosphorus is often sold for its vanadium content (up to 7 percent). The typical composition for a western ferrophosphorus product is given in Table 3-5.

The composition of ferrophosphorus is affected mainly by the excess carbon in the furnace charge. When highly reducing conditions exist in the furnace (larger than normal amounts of excess coke in the charge), part of the SiO_2 is reduced to silicon that combines with the ferrophosphorus, and the phosphorus content is thereby decreased. Ferrophosphorus is used largely as an alloying agent in the manufacture of steel. For this use, FeP containing a large percentage of phosphorus (a minimum of 22 percent) and only a small percentage of silicon is preferred. The furnace conditions required to produce high-grade ferrophsophorus result in slag that contains more than 1.0 percent P_2O_5. Since this results in inefficient furnace performance, high-grade ferrophosphorus is usually produced intentionally only when there is a demand for it. When the production of ferrophosphorus that contains at least 23 percent phosphorus is desired, the proportion of coke in the furnace charge is limited to 102 percent of the amount theoretically required.

3.2.4.3 Waste Materials

The major waste streams or materials at elemental phosphorus plants generally consist of:

- Scrubber slurries
- Phossy water (contains phosphorus)
- Dust from collection devices
- Metal or other scrap material

Process streams, such as scrubber slurries and phossy water, are typically sent to on-site settling ponds where the solids are allowed to precipitate. The water is then recovered and usually purified before being recycled to the plant for further use or disposal. Solids in the bottom of the ponds are normally dredged and, depending on their composition, either recycled to the plant or buried on site. At some plants, this material is occasionally sold.

Most dust materials from process collection devices are recycled back to the process. However, some of this material may be sent to on-site disposal (burial). In addition, cleanup fines from some plants are sent to on-site disposal. Scrap metal and other equipment components, such as carbon furnace materials or kiln linings, are either buried on site, stockpiled, or decontaminated and sold.

3.2.5 Airborne Emission Control Technology

Currently, no airborne emission control technologies are applied at elemental phosphorus plants to specifically limit the release of radioactivity. Airborne emission control technologies are generally used to limit release of particulates and fluorides. In doing so, however, they are also effective in reducing emissions of radioactive particulate material from the process. Requirements for airborne radionuclide emission control should be governed by the form and usage, the relative toxicity, and the quantity of material being handled.

Many different types of technologies are used to control airborne particulate emissions in elemental phosphorus plants. Among those most commonly used are wet scrubbers, wet and dry electrostatic precipitators (ESPs), and dry dust collectors. Scrubbers are used to remove particulates from gaseous streams through the physical and chemical interaction between the particulates and a scrubbing medium such as water. Depending on the scrubbing medium, scrubbers can also remove gaseous radioactive effluents. Among the most prevalent types of scrubbers are venturis, spray towers, cyclone spray scrubbers, and impingement scrubbers. Scrubber efficiencies depend on many factors including pressure drop across the device, particulate loading, system design, particle size, and chemical composition of the inlet process stream. Scrubbers normally require significantly more energy to operate than dry dust collectors and usually discharge liquid effluents, the volume of which depends on the operating conditions.

The process of electrostatic precipitation involves removing dust or liquid aerosol from a gas stream by imparting an electric charge to the contaminant and then passing the stream through an electric field. Electrostatic precipitators are particularly useful where high collection efficiencies for small particles are required from large volumes of effluents.

The efficiencies generally range from 98 percent to >99 percent. Energy use for electrostatic precipitators is generally comparable to that for scrubbers. Electrostatic precipitators usually discharge solid effluents, the magnitude of which depends on the operating conditions. Both wet and dry precipitators are used in elemental phosphorus plants.

Dry dust collectors are usually used on cool, dry effluents with suitable chemical compositions. The collectors most prevalent at elemental phosphorus plants are cyclones and baghouse fabric filters. Cyclone collectors offer one of the least expensive means of dust collection from both an operating and an investment standpoint. Cyclones for removing solids from gases are generally applicable when particles of over 5 μm diameter are involved. In collecting particles of over 200 μm diameter, cyclones may be used, but gravity settling chambers are usually satisfactory and less subject to abrasion.

In baghouse filter systems dust-laden gases pass through fabric filters. The dust is filtered out onto the fabric while the gas passes through. The pores in the cloth are typically many times the size of the dust particles separated. Thus, as the dust-laden gases pass through the fabric, the separation efficiency is low until enough particles have been removed to build up a "precoat" in the pores. Once this layer has formed, separation efficiencies are usually well over 99 percent. The energy requirements of dry dust collectors are comparatively less than for scrubbers or ESPs, but their maintenance costs are usually higher. Dry dust collectors usually discharge solid effluents, and filters from the collectors also must be disposed of.

In addition to the emission control technologies described above, most plants use secondary emission control methods largely for fugitive particulate emissions. These methods include operating in enclosed and ventilated areas for particularly dusty operations, partially enclosing most material handling and transfer equipment (e.g., conveyer belts), and using dust suppressant equipment in and around the plant (e.g., watering of roads).

3.3 PLANT PROCESS DESCRIPTIONS AND AIRBORNE EMISSIONS

This section describes specific plant sites, processes, materials, and radioactive emission sources and characteristics. Emissions of U-238, Th-230, Ra-226, Pb-210, and Po-210 were assessed for all plants. Uranium-234 emissions were not specifically addressed since these emissions should be identical to U-238. Radon-222 emissions from plant processes were not always assessed, but estimates of radon emanation rates from ore and slag stockpiles are presented where sufficient data exist.

Two basic methods were used to estimate emissions. The first and preferred method involved gathering and analysis of radioanalytical data of samples taken from process streams. Some of these data were published in technical reports or journals, while other data were contained only in company documents. If radionuclide emission rate data were not available, rates were estimated using particulate emission rate and expected radionuclide concentration of the particulate. The estimated annual emissions are conservative in that they represent the emission rate at full plant capacity (i.e., 24 hours per day, 365 days per year).

A note of caution should be added about the accuracy of the results. Many of the analytical results upon which the emission rate estimates are based are highly uncertain. Standard deviations of over 100 percent were associated with the counting statistics of many of the samples analyzed, especially those with very little activity. In addition, variations in process rates and conflicting information on many plant parameters tend to further compound the level of uncertainty. These factors tend to be most important for sources that have very low emission rates. Sources that emit significant amounts of radioactivity can be quantified more accurately. Levels of uncertainty are discussed further in the plant-specific subsections.

The principal sources of the estimated radioactive particulate emissions within each plant are discussed further in the applicable plant-specific subsections. For all plants, the most abundant radionuclides in airborne emissions are Pb-210 and Po-210. This is because lead and polonium can be volatilized in calcining and furnace processes and pass through air pollution control equipment more readily than nonvolatile particulate material. Radon-222 gas is also released in significant quantities from some plants. Following is a summary of the estimated airborne particulate radioactivity (Ci/yr) released from each facility at design capacity:

Plant	U-238	Th-230	Ra-226	Pb-210	Po-210
FMC, ID	0.008	0.011	0.011	0.038	8.2
Stauffer, MT	0.001	0.0015	0.0018	0.29	0.21
Stauffer, TN	0.001	0.00093	0.0012	0.038	0.024
Stauffer, FL	0.0051	0.0041	0.0049	0.23	0.17
Monsanto, TN	0.0067	0.006	0.0054	0.47	0.72
Monsanto, ID	0.00055	0.00051	0.00065	3.2	3.1
Mobil Chem., FL	0.0046	0.0046	0.0054	0.017	0.018
Occidental, TN	0.0023	0.0029	0.0026	0.20	0.23

3.3.1 FMC Plant - Pocatello, Idaho

3.3.1.1 The FMC Plant Site Characterization

The FMC elemental phosphorus plant is located at the edge of the Snake River Plain in southeastern Idaho at 112° 32' 0" longtitude and 42° 54' 30" latitude and at an elevation of 1372 m. It is 5.6 km northwest of the city of Pocatello on Interstate 15 and 4.8 km east of the city airport. The main lines of the Union Pacific railroad run on the northern boundary of the site, with spurs serving the plant. The plant is on the Portneuf River, which drains into the American Falls Reservoir on the Snake River 11.3 km northwest of the plant. The J. R. Simplot fertilizer plant is located immediately east of the FMC site. The area south of the plant contains large industrial waste ponds and beyond the waste ponds is the Caribou National Forest and Fort Hall Indian Reservation. Figure 3-5 shows the features of the area.

Meteorology and Air Quality

The area is semiarid, receiving an annual rainfall averaging 31 cm. The average annual temperature is 10.5°C. Winds are generally from the west or south, most frequently at 4 to 5 m/s.

Demography

The plant is in Power County, which had a population of 65,421 as of the 1980 census, or a population density of about 18 persons per km^2. The main population center near the plant, Pocatello, lies in Bannock county. Actual population density distributions around the plant are given in Appendix A.

Land Use

Fifty-five percent of Power county is used as farmland. Eighty-three percent of the farmland is used for food crops, and the other 17 percent is used for pasturage, primarily as rangeland.

Potatoes and food grains are the primary crops in the county. No leafy vegetables or exposed produce (fruits, squash, tomatoes, etc.) are commercially produced. Cattle are the primary meat animals raised . Only 2

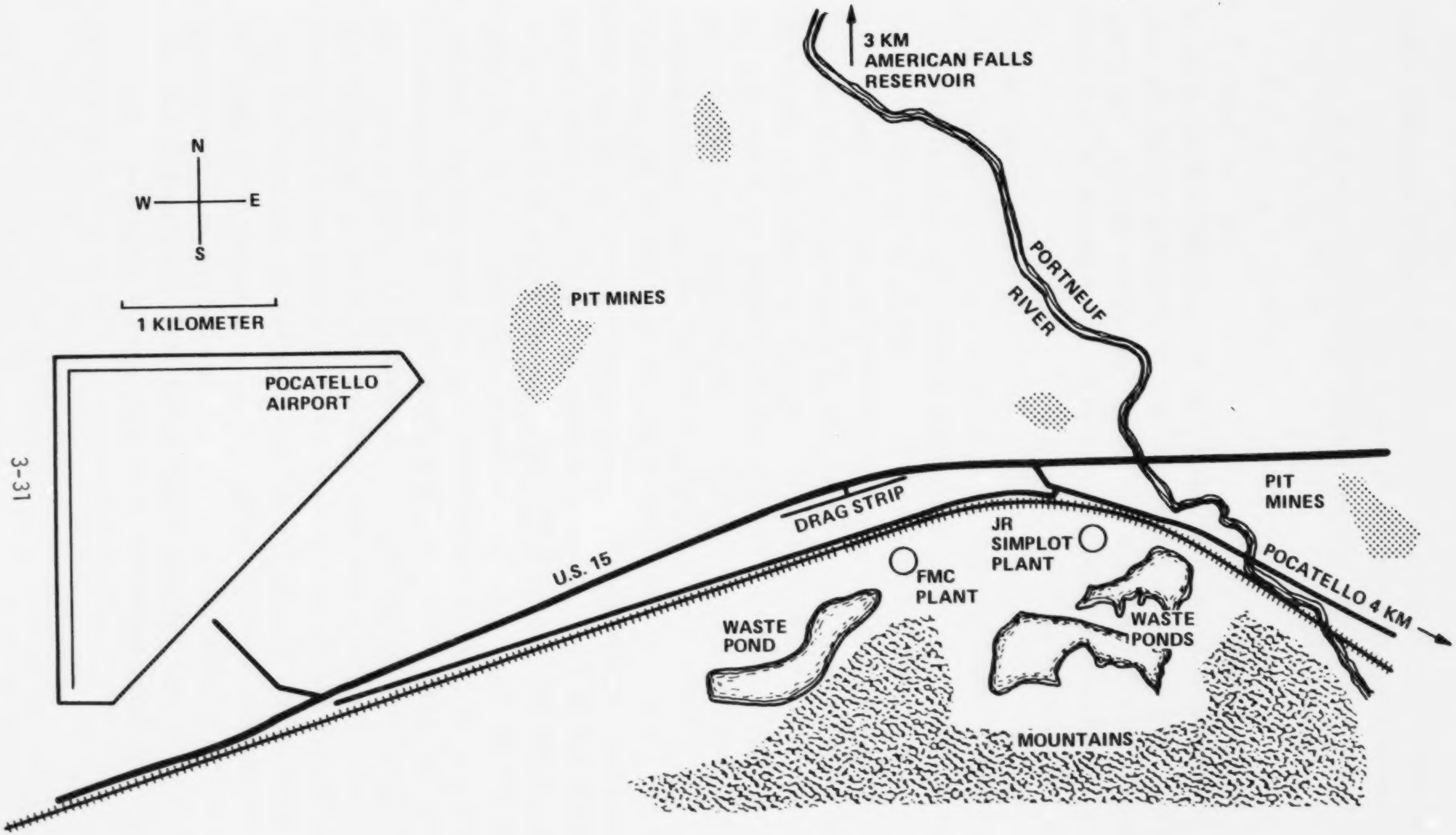

3 KM
AMERICAN FALLS
RESERVOIR
N
W
E
S
1 KILOMETER
PIT MINES
PORTNEUF
RIVER
POCATELLO
AIRPORT
DRAG STRIP
U.S. 15
JR
SIMPLOT
PLANT
FMC
PLANT
PIT
MINES
POCATELLO 4 KM
WASTE
POND
WASTE
PONDS
MOUNTAINS

Figure 3-5. FMC Plant Site Area.

percent of the total cattle population is used for dairy purposes. Only small numbers of hogs and sheep are raised.

Agricultural water sources account for less than 0.01 percent of the total county land area.

3.3.1.2 The FMC Process

Phosphate shale ore is shipped from the Gay Mine, located about 56 km northeast of the plant, to FMC by rail and is stockpiled during the six-month summer season for eventual use during the winter months. The plant operates 24 hours per day, 365 days per year. A schematic of the plant operations is provided as Figure 3-6 [19].

The ore rail cars are emptied by a rotary car-dumper into an underground hopper where conveyer belts transfer the ore to the stockpile. The stockpiled ore is subsequently screened and oversize material is transferred to an ore crusher; screened material is sent to the pelletizer building. There the ore is formed into briquettes by briquette presses. The briquettes are screened, the fines are recycled to the presses, and the briquettes are fed to two parallel traveling-grate calciners that operate at approximately 1260°C (2300°F). The calciners heat-harden the briquettes and volatilize compounds, including organics, carbon dioxide, fluorine, and moisture. The traveling-grate calciners are FMC-designed and patented. Each calciner is fueled with carbon monoxide generated in the electric furnace operation. The briquetting and briquette-calcining steps are FMC's process equivalent to the basic process flowsheet operation referred to as nodulizing. The offgas from each calciner is vented into a duct that equally distributes the flow to two wet scrubbers (four total). The wet scrubbers use recycled process water to remove fluorine, P_2O_5, and particulates. The nodules (calcined briquettes) are stockpiled or transferred to the proportioning building storage hoppers. The nodules are mixed with coke and silica using a proportioning weighing system. This mixture, called furnace burden, is conveyed to the burden level of the furnace building (located above the furnaces) and gravity fed to the four electric reduction furnaces.

The furnaces operate continuously and are periodically tapped to remove the molten calcium silicate slag and ferrophosphorus. Each furnace has four tapholes: east and west tapholes for silicate slag and east and west tapholes for ferrophosphorus. Slag taps usually occur every hour for

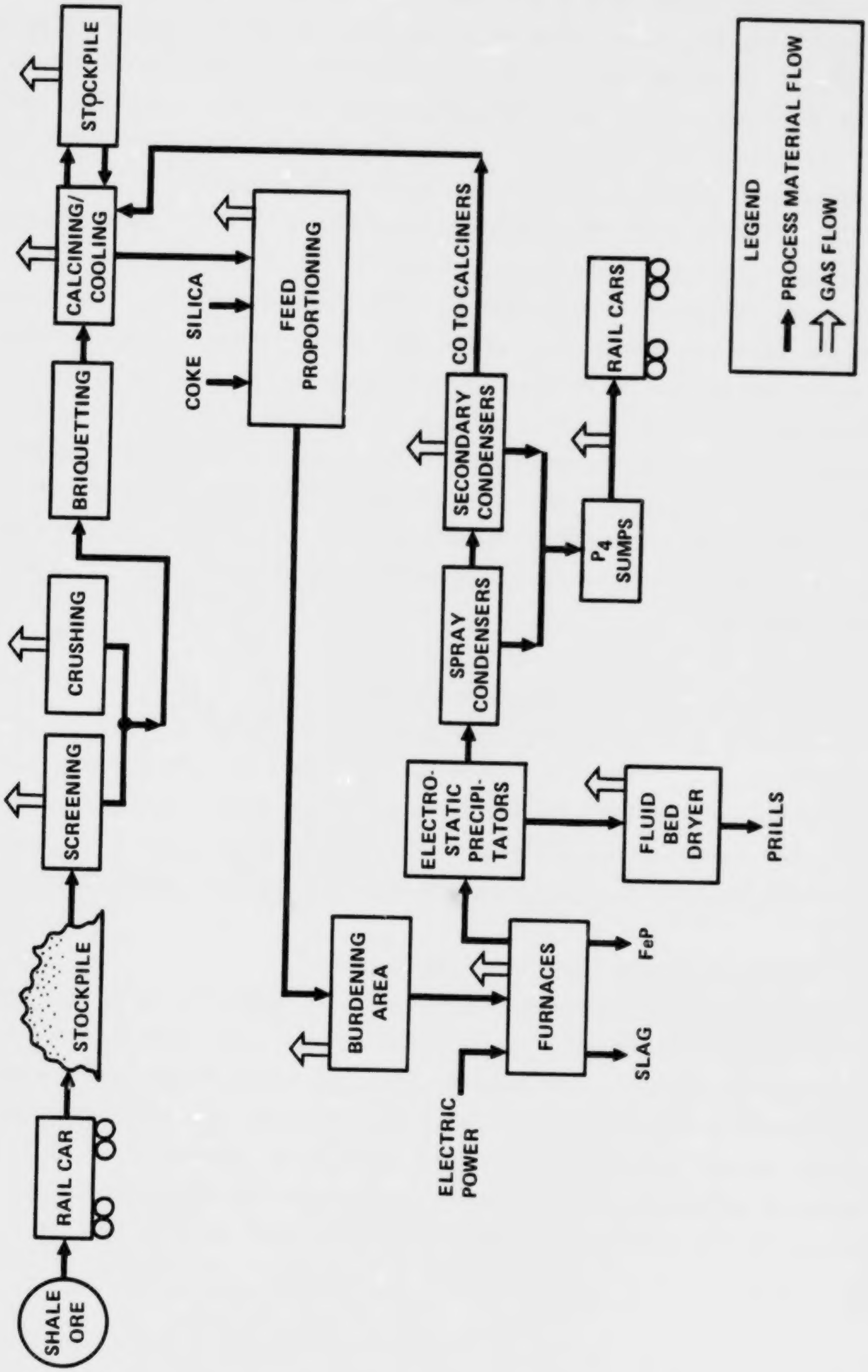

SHALE ORE
RAIL CAR
STOCKPILE
SCREENING
CRUSHING
BRIQUETTING
CALCINING/ COOLING
STOCKPILE
COKE
SILICA
FEED PROPORTIONING
BURDENING AREA
ELECTRIC POWER
FURNACES
SLAG
FeP
ELECTRO-STATIC PRECIPI-TATORS
FLUID BED DRYER
PRILLS
SPRAY CONDENSERS
SECONDARY CONDENSERS
CO TO CALCINERS
P4 SUMPS
RAIL CARS
LEGEND
PROCESS MATERIAL FLOW
GAS FLOW

Figure 3-6. Simplified Process Flow Diagram for the FMC Plant [19].

20 minutes and ferrophosphorus taps occur about every 16 hours for 30 minutes. The slag pours into a pit, adjacent to the furnace building, where it is cooled and fractured with water sprays. After the molten slag has solidified, it is loaded into trucks by a front-end loader and hauled to an aggregate plant or stockpiled. Ferrophosphorus is tapped into chill molds located inside the furnace building and air cooled. The ferrophosphorus molds are sold to metal processors who recover the vanadium.

The offgases from the furnaces, composed mainly of carbon monoxide and phosphorus, are drawn through an electrostatic precipitator (one per furnace) where particulates are removed. The cleaned gases are sent through primary and secondary condensers where the gases are cooled and phosphorus condenses. Most of the CO is then routed to the calciners and burned. The remaining CO is either routed to ESP dust processing or flared to the atmosphere. The condensed phosphorus is collected in sumps and pumped to storage where it is stored under a water seal to prevent contact with air. The stored phosphorus is bottom loaded into rail cars for shipment to FMC chemical plants where it is combined with other elements to make various phosphate compounds.

3.3.1.3 FMC Feed Materials Characterization

The FMC plant uses the same feed materials as the basic process plant described in Section 3.2. Table 3-6 provides the sources and typical values for the composition, quantities used per short ton of phosphorus produced, and radionuclide content of these feed materials. The range of values for the typical quantity reported is estimated as ± 10 percent.

3.3.1.4 FMC Product Materials Characterization

The FMC plant produces the same basic products as described in Section 3.2: elemental phosphorus, ferrophosphorus, and slag. In addition, FMC processes the particulates removed from the electric furnace offgas to produce a product called prills. Table 3-7 provides the sales destination and typical values for the composition, quantities produced per short ton of phosphorus produced, and radionuclide content for these products. The range of values for the typical quantity is estimated as ± 10 percent.

Table 3-6. FMC Phosphorus Plant Feed Materials Characterization.

Characteristic	Phosphate Ore	Coke	Silica
1. Source(1)	Gay Mine (Idaho)	80% - FMC coke plant (Kemmerer, Wyoming) 20% - Various manufacturers	Mined adjacent to FMC plant
2. Chemical Composition, wt % (1)			
P_2O_5	24.0	-	-
SiO_2	24.3	3.3	96.0
CaO	35.0	-	0.25
Al_2O_3	4.2	1.3	1.5
Fe_2O_3	1.4	0.3	1.0
C	2.1	90.9 (dry basis)	-

Table 3-6. FMC Phosphorus Plant Feed Materials Characterization. (Continued)

Characteristic	Phosphate Ore	Coke	Silica
3. Radionuclide content (pCi/g)(2)			
U-238	22	0.5	1.5
Th-230	22	0.2	1.6
Ra-226	22	0.8	1.7
Pb-210	27	2.4	0.7
Po-210	22	1.3	2.6
4. Feed material(1) utilization (ton/ton P_4 produced)	12.0	1.4	0.8
5. Electrical power(1) (kWh/short ton P_4 produced)	~13,000		

(1) Data presented to SAI staff at November 1, 1982, meeting at FMC Corporation's Elemental Phosphorus Plant in Pocatello, Idaho.

(2) Data from Ref. [20].

Table 3-7. FMC Phosphorus Plant Product Materials Characterization.

Characteristic	Phosphorus	Slag	Ferrophosphorus	Prills
1. Sales Destination(1)	FMC chemical plants	Bannock Paving Co.	Union Carbide Company	Soda Springs Phosphate Co.
2. Utilization(1)	Chemicals production	As aggregate rock	For vanadium metal recovery	Fertilizer
3. Chemical Composition, wt %(1)				
SiO_2	-	42	-	13.9
CaO	-	44	-	10
Al_2O_3	-	6	-	-
Fe_2O_3	-	0.4	-	-
P_2O_5	-	1.7	-	27.2
P	>99.9	-	26.2	-
Fe	-	-	58	-
V	-	-	4.7	-
Cr	-	-	4.1	-

Table 3-7. FMC Phosphorus Plant Product Materials Characterization. (Continued)

Characteristic	Phosphorus	Slag	Ferrophosphorus	Prills
4. Radionuclide content, pCi/g[2]				
U-238	-	23	19	71
Th-230	-	27	0.4	24
Ra-226	0.02	28	0.3	13
Pb-210	0.2	11	1.1	52
Po-210	-	7.6	0.5	440
5. Production (ton/ton P_4 produced)[1]	1.0	9.8	0.17	0.14

(1) Data presented to SAI staff at November 1, 1982, meeting at FMC Corporation's Elemental Phosphorus Plant in Pocatello, Idaho.

(2) Data from Ref. [20].

3.3.1.5 FMC Plant Waste Materials

The FMC plant has a minor quantity of waste materials. Only the phossy water and phossy waste remain on site in appreciable quantities; however, the water is recycled. The settled waste in the polyvinyl chloride-lined phossy water ponds is currently being evaluated by FMC to determine its ultimate disposition.

Used furnace brick is stored on site and is either recycled or periodically sold for salvage value. All metal and other slag are stockpiled and sold at salvage value.

3.3.1.6 FMC Process Airborne Emissions and Sources Characterization

A key objective of this project was to identify and characterize the major airborne emission points. Emission characterization focused on both gaseous and solid radionuclides. To fulfill this objective, the plant operating permits, located at the Idaho Department of Health and Welfare in Boise, Idaho, were copied and reviewed. The FMC elemental phosphorus plant was toured on November 1, 1982, and technical discussions were held with key plant staff. In addition, a literature review was completed.

The process airborne emission points were divided into three groups: points sources, vents, and fugitive sources. This section only reports emission sources and characterizes emissions. The related air pollution control equipment is described in Chapter 4.

Point Sources

Table 3-8 lists the air pollution sources, emission points, and control equipment (characterized in Chapter 4). Point source emissions are generally continuous.

Vents

Table 3-9 lists vents, including emergency vents, air pollution sources, emission points, and control equipment (characterized in Chapter 4). Vent emissions are intermittent.

Table 3-8. Point Sources of Airborne Emissions for the FMC Plant.

Air Pollution Source	Emission Points	Control Equipment
Enclosed shale crushing operation and covered conveying system	East shale baghouse (handling and transfer points)	Baghouse
	Middle shale baghouse (crushing and screening building)	Baghouse
	West shale baghouse (handling and transfer points)	Baghouse
#1 calciner and cooler	#1 calciner/#1 scrubber stack #1 calciner/#2 scrubber stack	2 scrubbers in parallel
	#1 calciner/#1 cooler (split stack) #1 calciner/#2 cooler (split stack)	Baffled settling chamber for each cooler
#2 calciner and cooler	#2 calciner/#1 scrubber stack #2 calciner/#2 scrubber stack	2 scrubbers in parallel
	#2 calciner/#1 cooler stack #2 calciner/#2 cooler stack	Baffled settling chamber for each cooler
Nodule stockpile	Nodule stockpile baghouse	Hoods, covered conveyer system, and baghouse
Nodule reclaim	North nodule reclaim baghouse	Hoods, covered conveyer system, and baghouse
	South nodule reclaim baghouse	Hoods, covered conveyer system, and baghouse
Proportioning building	East nodule baghouse	Hoods, covered conveyer system, and baghouse

Table 3-8. Point Sources of Airborne Emissions for the FMC Plant. (Continued)

Air Pollution Source	Emission Points	Control Equipment
	West nodule baghouse	Hoods, covered conveyer system, and baghouse
Coke handling	Coke handling baghouse	Hoods, covered conveyer system, and baghouse
#1 electric arc furnace slag and metal tapping operations	#1 Andersen stack	Hoods, crossover system, 2 Medusa venturi scrubbers and an Andersen filter media scrubber control system
#2 electric arc furnace slag and metal tapping operations	#2 Andersen stack	Hoods, crossover system, 2 Medusa venturi scrubbers and an Andersen filter media scrubber control system
#3 electric arc furnace slag and metal tapping operations	#3 Andersen stack	Hoods, crossover system, 2 Medusa venturi scrubbers and an Andersen filter media scrubber control system
#4 electric arc furnace slag and metal tapping operations	#4 Andersen stack	Hoods, crossover system, 2 Medusa venturi scrubbers and an Andersen filter media scrubber control system
Phosphorus loading dock	Phosphorus dock scrubber stack	Andersen filter media scrubber
Slurry handling	Fluid bed dryer scrubber stack	2 stage ESP and Medusa venturi scrubber

Table 3-8. Point Sources of Airborne Emissions for the FMC Plant. (Continued)

Air Pollution Source	Emission Points	Control Equipment
Burden area above #1 and #2 furnace	#1 baghouse stack	Baghouse
Burden area above #3 and #4 furnace	#2 baghouse stack	Baghouse
Silo baghouse	Silo baghouse stack (non-CO gas stream)	Baghouse

Table 3-9. Vents and Emergency Vents at the FMC Plant.

Air Pollution	Emission Point	Control Equipment
Furnace phosphorus sumps	#1 furnace sump vent	Vented to Medusa scrubber
	#2 furnace sump vent	-
	#3 furnace sump vent	-
	#4 furnace sump vent	Vented to Medusa scrubber
Furnace pressure relief valve (PRV)	#1 furnace PRV	-
	#2 furnace PRV	-
	#3 furnace PRV	-
	#4 furnace PRV	-
Furnace CO flares	#1 furnace CO flare	-
	#2 furnace CO flare	-
	#3 furnace CO flare	-
	#4 furnace CO flare	-
Slurry tank vent	Tank vent	-
Elevated CO flare	Flare	-
CO flare pit	Flare	-

Fugitive Sources

The fugitive emission sources are the slag pit and slag handling operations, miscellaneous furnace leaks (including electrode seals), the plant roads, and material stockpiles. Each of these areas is discussed below.

- Slag Pit and Slag Handling

  The slag pit and slag handling operations are defined as fugitive emission sources. The molten slag tapped from the furnaces flows by gravity into a pit located adjacent to the furnace building. Immediately after the tap is completed, water is sprayed onto the molten slag for 15 minutes, turned off for 5 minutes, and turned back on for another 15 minutes. The sprays cool and fracture the slag before a front-end loader digs and loads the slag into a truck. The slag is then hauled and sold to a nearby aggregate plant. This digging and loading operation raises a cloud of water vapor, dust, and P_2O_5 fumes.

- Miscellaneous Furnace Leaks

  Each furnace has three carbon electrodes that are continuously fed into the furnace. To prevent furnace gas from leaking around the electrodes, they are equipped with double inert gas seals. However, infrequent pressure surges caused by bridging and collapse of material in the furnace break the seals and allow gases to leak into the building.

- Plant Roads

  The plant roads are not paved, and travel on these roads causes fugitive dust emissions. The biggest problems are on the haul roads used by slag-hauling trucks. FMC uses $MgCl_2$ on all unpaved roads as a dust suppressant.

- Stockpiles

  The stockpiles of ore and nodules are not generally a problem because of the moisture content of the ore. However, during dry conditions, dust from the stockpiles can be a problem. The nodule reclaim stockpiles have ladders on all discharge points together with a baghouse. Free-fall occurs within the ladders, and any dust generated is collected.

Key Sources of Radionuclide Emissions

The estimated annual particulate radionuclide emissions to air from the FMC plant are summarized in Table 3-10. Information shown in Table 3-10 was obtained from many sources including Ref. [19], data obtained directly from FMC, and data obtained from the Idaho Department of Health and Welfare - Division of Environment. The calciner stacks are the most important sources of radioactive emissions, and Po-210, volatilized by the calcining process, is by far the most important radionuclide. The combined Po-210 emission rate for the four calciner stacks is approximately 242,000 pCi/s (7.6 Ci/yr). But the radioanalytical results upon which these estimates were made [20] are highly uncertain. Since the source of uncertainty tends to be more important for low-level samples, the level of error is probably not significant for the calciner stack sampling results. Another result of this uncertainty, however, could be the underestimation of the Pb-210 content of plant discharges.

A significant amount of Po-210 is also emitted from the calciner cooler stacks (0.24 Ci/yr), the fluid bed dryer stack (0.35 Ci/yr), and the furnace taphole system stacks (0.038 Ci/yr). These stacks are also significant sources of non-volatile particulate radionuclide emissions but at rates much less than for Po-210.

Data necessary to calculate radon emanation rates at the FMC plant are not available. However, radon generation from the slag does not appear to exceed that from local dirt or non-slag aggregate.

Activity Balance

The flow of radioactivity through the FMC plant process is illustrated in Figure 3-7. These estimates indicate that virtually all the input U-238, Th-230, and Ra-226 is accounted for in the output slag, and to a much lesser extent, in the fluid bed prills and ferrophosphorus. Much of the Pb-210 and Po-210, however, is unaccounted for and presumably has been transported by scrubber effluents to the liquid settling ponds. However, some of the stack sampling results may have underestimated the Pb-210 content, in

Table 3-10. Stack and Emission Data for the FMC Elemental Phosphorus Plant.

Source	Stack Geometry		Stack Gas Characteristics				Particulate Emissions		Radionuclide Emissions pCi/s (Ci/yr)				
	Height (m)	Diameter (m)	Flow (ACMM)	Exit Velocity (m/s)	Exit Temperature C° (K°)	Heat Release (cal/s)	(g/m^3)	(g/s)	U-238	Th-230	Ra-226	Pb-210	Po-210
Ore handling and transfer points(1)	4.0	0.4	142	18.8	21 (294)	7.5×10^3	0.0068	0.016	0.35	0.35	0.42	0.43	0.35
Crushing/briquetting transfer points(1)	5.5	0.8	481	15.9	21 (294)	2.5×10^4	0.0026	0.021	0.46	0.46	0.55	0.57	0.46
Ore crushing/ screening(1)	11.3	0.5	283	24.0	21 (294)	1.5×10^4	0.017	0.079	1.7	1.7	2.1	2.1	1.7
Calciner #1 stack 1-1(2)	30.8	2.1	3059	14.7	54 (327)	5.9×10^5	0.091	4.64	10	18	10	32	55,000
Calciner #1 stack 1-2(2)	30.8	2.1	3557	17.0	54 (327)	6.9×10^5	0.065	3.85	12	21	11	38	64,000
Calciner #2 stack 2-1(2)	30.8	2.1	3296	15.9	54 (327)	6.5×10^5	0.054	2.94	11	19	11	35	59,000
Calciner #2 stack 2-2(2)	30.8	2.1	3619	17.4	54 (327)	7.0×10^5	0.038	2.31	12	21	12	38	64,000
Calciner cooler stack 1-1(2)	12.8	2.4	2450	9.0	316 (589)	1.85×10^6	0.0096	0.39	34	50	45	86	1,600
Calciner cooler stack 1-2(2)	12.8	2.4	2470	9.1	204 (477)	1.45×10^6	0.018	0.76	34	50	45	86	1,600
Calciner cooler stack 2-1(2)	12.5	1.8	3390	22.2	316 (589)	2.57×10^6	0.044	2.50	46	64	61	120	2,200
Calciner cooler stack 2-2(2)	12.5	1.8	3342	21.9	204 (477)	1.95×10^6	0.033	1.84	46	64	61	120	2,200
Nodule stockpile(3)	-	-	566	-	-	-	0.001	0.01	0.24	0.23	0.25	0.18	0.026
Nodule transfer point(3)	15.2	0.9	736	19.3	32 (305)	7.5×10^4	0.011	0.139	3.3	3.2	3.5	2.5	0.36
Nodule reclaim area(3)	15.2	0.9	736	19.3	32 (305)	7.5×10^4	0.011	0.139	3.3	3.2	3.5	2.5	0.36
Proportioning area nodule handling system stack 1(3)	12.8	0.9	595	15.6	21 (294)	3.06×10^4	0.014	0.139	3.3	3.2	3.5	2.5	0.36

Table 3-10. Stack and Emission Data for the FMC Elemental Phosphorus Plant. (Continued)

Source	Stack Geometry		Stack Gas Characteristics				Particulate Emissions		Radionuclide Emissions pCi/s (Ci/yr)				
	Height (m)	Diameter (m)	Flow (ACMM)	Exit Velocity (m/s)	Exit Temperature C° (K°)	Heat Release (cal/s)	(g/m^3)	(g/s)	U-238	Th-230	Ra-226	Pb-210	Po-210
Proportioning area nodule handling system stack 2$^{(3)}$	12.8	0.9	595	15.6	21 (294)	3.1×10^4	0.014	0.139	3.3	3.2	3.5	2.5	0.36
Proportion area coke handling$^{(4)}$	12.8	0.9	595	15.6	21 (294)	3.1×10^4	0.013	0.126	0.06	0.03	0.1	0.3	0.16
Silo baghouse$^{(3)}$	24.1	0.9	765	20.0	21 (294)	3.9×10^4	0.008	0.10	2.4	2.3	2.5	1.8	0.26
Burdening area stack 1(E)$^{(3)}$	34.1	1.5	2265	21.4	21 (294)	1.2×10^5	0.004	0.18	4.3	4.1	4.5	3.2	0.18
Burdening area stack 1(W)$^{(3)}$	34.1	1.5	2265	21.4	21 (294)	1.2×10^5	0.005	0.23	5.5	5.3	5.8	4.1	0.6
CO flares			---------- Negligible Amounts of Radioactivity ----------										
P_4 loading dock	15.2	1.2	708	10.4	32 (305)	7.2×10^4	0.008	0.10	---------- Negligible Radioactivity ----------				
Fluid-bed dryer$^{(2)}$	38.1	2.1	2050	9.9	32 (305)	2.1×10^5	0.074	2.52	3.1	0.4	26	200	11,000
Furnace #1 taphole$^{(2)}$	31.4	1.2	1133	16.7	32 (305)	1.2×10^5	0.024	0.45	2.5	0.8	7.0	100	300
Furnace #2 taphole$^{(2)}$	31.4	1.2	1133	16.7	32 (305)	1.2×10^5	0.013	0.24	2.5	0.8	7.0	100	300
Furnace #3 taphole$^{(2)}$	31.4	1.2	1133	16.7	32 (305)	1.2×10^5	0.017	0.32	2.5	0.8	7.0	100	300
Furnace #4 taphole$^{(2)}$	31.4	1.2	1133	16.7	32 (305)	1.2×10^5	0.018	0.34	2.5	0.8	7.0	100	300
Totals									250 (0.008)	340 (0.011)	340 (0.011)	1200 (0.038)	260,000 (8.2)

(1) Assumes radionuclide concentrations of particulate emissions same as that of PO_4 ore.

(2) Calculated from radionuclide concentrations in stack air [20], and corrected for temperature, pressure, and moisture content.

(3) Assumes radionuclide concentrations of particulate emissions same as that of nodules.

(4) Assumes radionuclide concentrations of particulate emissions same as that of coke.

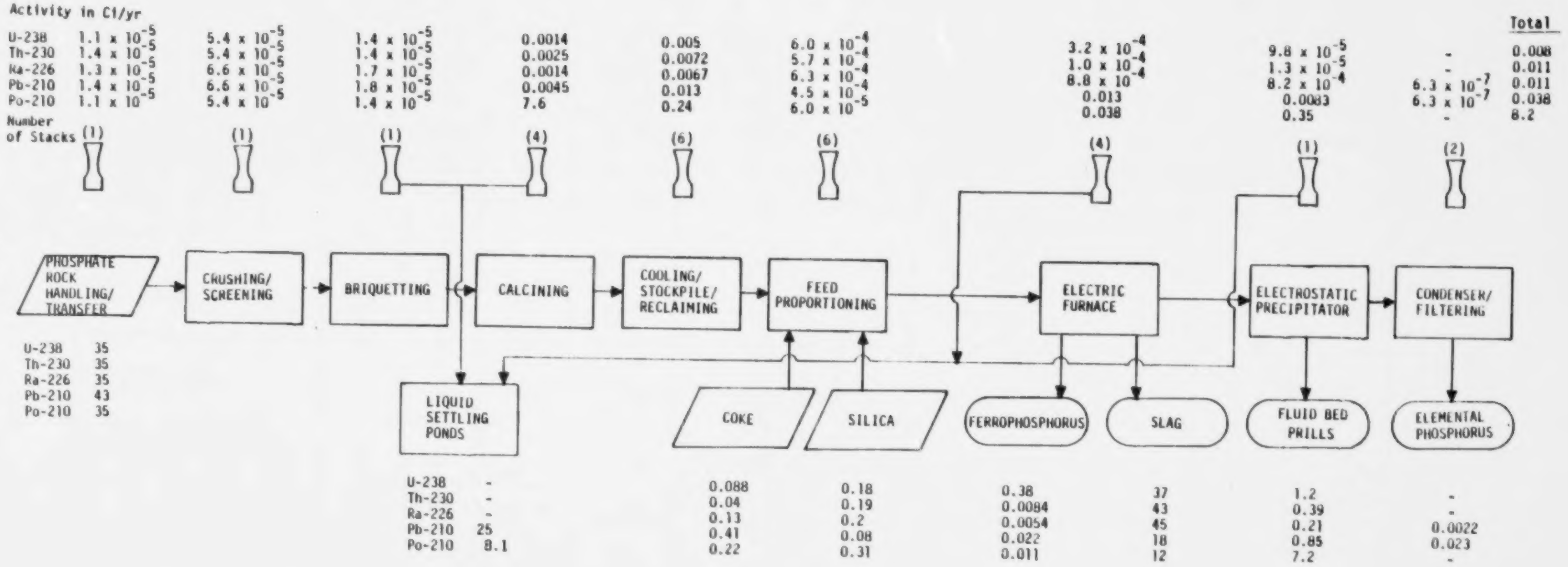

Activity in Ci/yr
U-238 1.1 x 10^{-5}
Th-230 1.4 x 10^{-5}
Ra-226 1.3 x 10^{-5}
Pb-210 1.4 x 10^{-5}
Po-210 1.1 x 10^{-5}
Number of Stacks (1)
5.4 x 10^{-5}
5.4 x 10^{-5}
6.6 x 10^{-5}
6.6 x 10^{-5}
5.4 x 10^{-5}
(1)
1.4 x 10^{-5}
1.4 x 10^{-5}
1.7 x 10^{-5}
1.8 x 10^{-5}
1.4 x 10^{-5}
(1)
0.0014
0.0025
0.0014
0.0045
7.6
(4)
0.005
0.0072
0.0067
0.013
0.24
(6)
6.0 x 10^{-4}
5.7 x 10^{-4}
6.3 x 10^{-4}
4.5 x 10^{-4}
6.0 x 10^{-5}
(6)
3.2 x 10^{-4}
1.0 x 10^{-4}
8.8 x 10^{-4}
0.013
0.038
(4)
9.8 x 10^{-5}
1.3 x 10^{-5}
8.2 x 10^{-4}
0.0083
0.35
(1)
-
-
6.3 x 10^{-7}
6.3 x 10^{-7}
-
(2)
Total
0.008
0.011
0.011
0.038
8.2
PHOSPHATE ROCK HANDLING/ TRANSFER
CRUSHING/ SCREENING
BRIQUETTING
CALCINING
COOLING/ STOCKPILE/ RECLAIMING
FEED PROPORTIONING
ELECTRIC FURNACE
ELECTROSTATIC PRECIPITATOR
CONDENSER/ FILTERING
U-238 35
Th-230 35
Ra-226 35
Pb-210 43
Po-210 35
LIQUID SETTLING PONDS
COKE
SILICA
FERROPHOSPHORUS
SLAG
FLUID BED PRILLS
ELEMENTAL PHOSPHORUS
U-238 -
Th-230 -
Ra-226 -
Pb-210 25
Po-210 8.1
0.088
0.04
0.13
0.41
0.22
0.18
0.19
0.2
0.08
0.31
0.38
0.0084
0.0054
0.022
0.011
37
43
45
18
12
1.2
0.39
0.21
0.85
7.2
-
-
0.0022
0.023
-

Figure 3-7. Activity Balance for the FMC Plant.

which case the emissions of this radionuclide would be higher [20]. Differences in total Ci/yr between input and output streams for specific radionuclides are attributed to uncertainty in analytical data.

Approximately one-third of the input Po-210 is contained in the slag; one-fourth is discharged to air; one-fourth is transported to the liquid settling ponds; and one-fifth is contained in the fluid bed prills.

3.3.2 Stauffer Chemical Plant - Silver Bow, Montana

3.3.2.1 Stauffer Chemical-Montana Plant Site Characterization

The Stauffer Chemical-Montana plant is located in Silver Bow, Montana, at 112° 40' 0" longitude and 45° 59' 30" latitude and an elevation of 1707 m. It is 12.9 km west of the town of Butte in the center of a high-density mining area. The plant is within a kilometer south of the junction of Interstate Highways 15 and 90 and lies between the Deerlodge and Beaverhead National Forests. The Silver Bow Creek and main lines of the Burlington Northern railroad lie north of the plant, with railway spurs serving the plant. The plant lies in a narrow valley in the middle of a large mountainous region. A map of the area and its major features is shown in Figure 3-8.

Meteorology and Air Quality

The area is semiarid, receiving rainfall averaging 38 cm annually. The average annual temperature is 4.6°C. Winds in the area are generally from the west and range from 2 to 5 m/s.

Demography

The plant is located in Silver Bow county which had a population of 38,092 or 20 persons per km^2, as of the 1980 census. Actual population distributions around the plant are given in Appendix A.

Land Use

Twenty-nine percent of the county is farmland of which 8 to 9 percent is rangeland. Food grains are the only food crop produced in the county. Beef cattle are the primary animals raised; only small numbers of milk cows, hogs, sheep and chickens are raised. Agricultural ponds account for less than 0.02 percent of the county land area.

3.3.2.2 The Stauffer Chemical-Montana Process

Phosphate ore from the Wooley Valley, Idaho, mine is shipped to the plant by rail during the six-month summer season and stockpiled for winter use. In addition, an approximate six-month contingency ore supply is stockpiled. Thus, a maximum stockpile amounting to about a one-year supply at plant design capacity is accumulated near the end of summer. The plant operates 24 hours per day, 365 days per year. A schematic of plant operations is provided as Figure 3-9.

The ore cars are emptied into a pit from which hooded conveyer belts transfer the ore to either of two large stockpiles. The process of ore blending is initiated here by layering the ore as it is stockpiled. Ore is removed from one stockpile while the other stockpile is being accumulated. The ore is further blended during ore removal by large scrapers which deliver the ore to a transfer pit where hooded belt conveyers move it to feed hoppers in the kiln feed building. The kiln feed hoppers include fines recycle feed hoppers for coke, nodule and ore transfer dust. The hoppers provide blended feed ore and recycle dust to the two rotary kilns by hooded belt conveyer feeders.

The rotary kilns produce large, stable agglomerates (nodules), which are required for proper operation of the electric reduction furnaces. The rotary kilns heat the ore to its incipient melting point (about 1300°C), and the tumbling action causes the ore to agglomerate into the desired nodular form. The rotary kilns are fueled with carbon monoxide generated in the electric reduction furnace operation.

The kiln offgas is vented into kiln-specific and identical offgas treatment operations consisting of a multiclone (six cyclones per kiln), a spray scrubbing tower, and a wet electrostatic precipitator. The wet scrubber uses a lime scrubbing liquor to remove fluorine, P_2O_5, and particulates. The offgas stream from each nodule cooler is treated sequentially by a multicyclone and a wet scrubber (duplicate equipment for each system). The hot nodules are passed through kiln-specific processing sequences of nodule cooling, crushing, and screening. Offgas from each nodule crushing/sizing operation is treated by a separate wet scrubber. The appropriately sized nodular material is sent to nodule storage, and the fines are either recycled through the nodulizing kilns or sent to the phosphorus sludge roaster.

The phosphorus sludge roaster is a rotary kiln that also receives the sludge resulting from the phosphorus filtering operation described later. The sludge roasting operation is used to recover residual phosphorus. Some roaster product is spread on the ore stockpile to prevent the

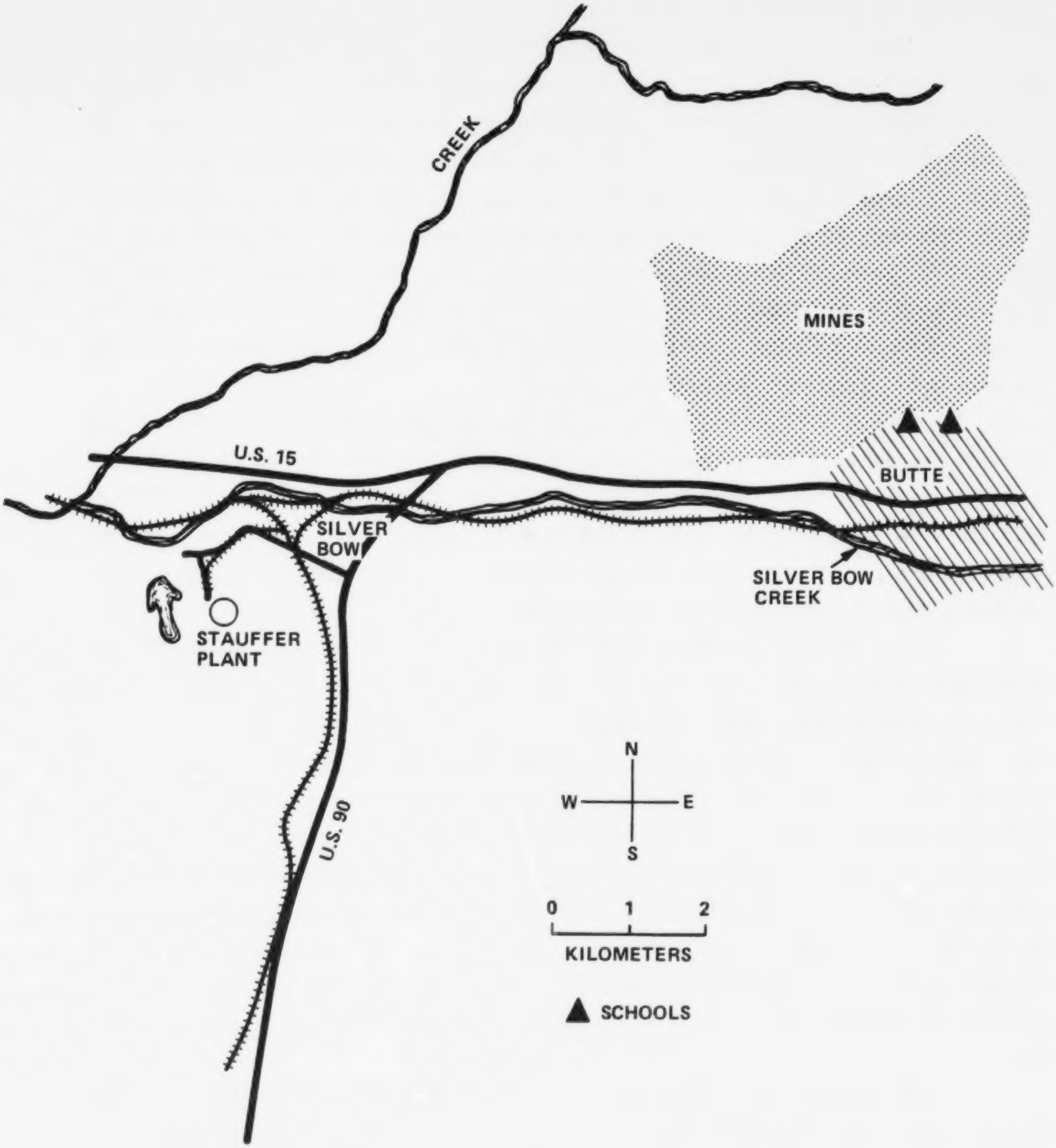

CREEK
MINES
U.S. 15
BUTTE
SILVER BOW
SILVER BOW CREEK
STAUFFER PLANT
U.S. 90
N
W
E
S
0
1
2
KILOMETERS
▲ SCHOOLS

Figure 3-8. Stauffer Chemical-Montana Plant Site Area.

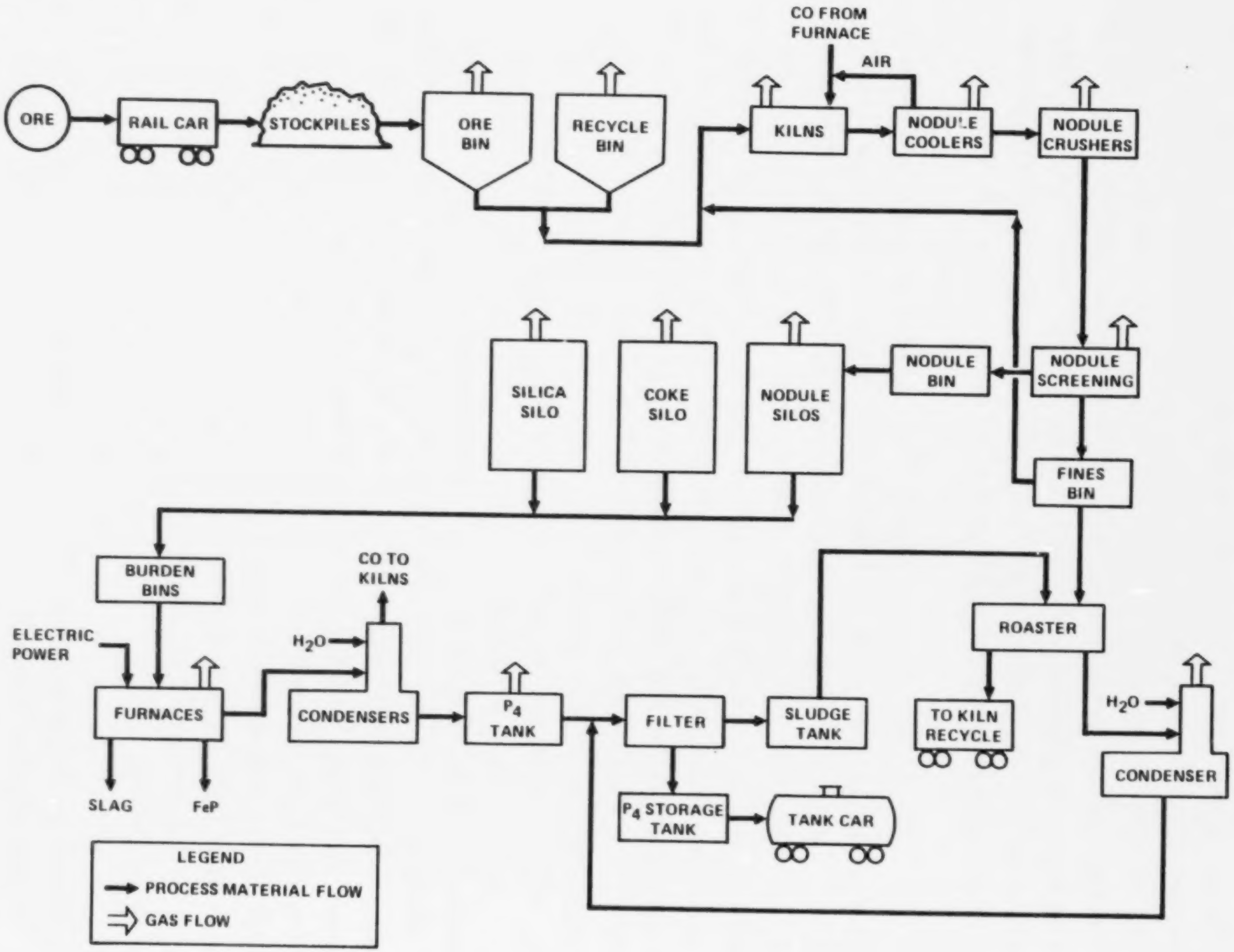

CO FROM FURNACE
AIR
ORE
RAIL CAR
STOCKPILES
ORE BIN
RECYCLE BIN
KILNS
NODULE COOLERS
NODULE CRUSHERS
SILICA SILO
COKE SILO
NODULE SILOS
NODULE BIN
NODULE SCREENING
FINES BIN
BURDEN BINS
CO TO KILNS
ELECTRIC POWER
H_2O
FURNACES
CONDENSERS
P_4 TANK
FILTER
SLUDGE TANK
ROASTER
TO KILN RECYCLE
H_2O
CONDENSER
SLAG
FeP
P_4 STORAGE TANK
TANK CAR
LEGEND
PROCESS MATERIAL FLOW
GAS FLOW

Figure 3-9. Simplified Process Flow Diagram for the Stauffer Chemical-Montana Plant.

damp ore from freezing and hampering winter operations. The roaster offgases are treated with a wet scrubber.

Following the sizing operation, the nodular material is sent to the proportioning building where it is stored in five nodule storage silos. Metallurgical grade coke is dried and sized on site and then stored in the coke storage silo in the proportioning building. Locally mined silica is stored in the silica storage silo. The nodules, coke, and silica are mixed using a proportioning weighing system. This mixture, called furnace burden, is moved by hooded belt conveyer to a skip hoist that loads the material into the elevated burden bins. The enclosed and pressurized burden bins are located above the furnaces and continuously feed the furnaces by gravity.

At this plant, Stauffer Chemical operates two electric reduction furnaces that operate at 1400 to 1800°C. The furnaces operate continuously and are periodically tapped to remove the molten slag and ferrophosphorus that accumulate at the bottom. Slag taps occur approximately every 2 hours for 30 to 45 minutes, and ferrophosphorus taps occur approximately every 8 hours for about 20 minutes. The slag pours into a water-filled slag granulation pit adjacent to the furnace building. The water causes the slag to cool and become granulated. After cooling, the slag is loaded into trucks by a front-end loader and hauled to a stockpile. The ferrophosphorus is chilled, crushed, and sold to metal processors for vanadium recovery.

The furnace offgases, composed of mainly carbon monoxide and phosphorus, are drawn through an electrostatic precipitator (one per furnace) where particulates are removed. The cleaned gases are then sent through a condenser (one per furnace) where the gases are cooled and the phosphorus condenses. The CO is then either routed to the rotary kilns and burned or flared to atmosphere. The condensed phosphorus is collected in tanks, filtered, and displaced to underwater storage. The stored phosphorus is top loaded into water-sealed railroad cars for shipment to Stauffer Chemical plants where it is combined with other elements to make various phosphate compounds.

3.3.2.3 Stauffer Chemical-Montana Plant Feed Materials Characterization

The Stauffer Chemical-Montana plant uses the same feed materials as the basic process plant described in Section 3.2. Table 3-11 provides the

Table 3-11. Stauffer Chemical-Montana Phosphorus Plant Feed Materials Characterization.

Characteristic	Phosphate Ore	Coke	Silica
1. Source (1)	Wooley Valley, Idaho Mine	Mid-Continental Coal Co.	Mined adjacent to plant
2. Chemical composition, wt %(1)			
P_2O_5	27.0	-	-
SiO_2	24.0	3.2	97.0
CaO	34.5	-	0.3
Al_2O_3	4.0	1.2	1.5
Fe_2O_3	2.0	0.3	1.0
C	2.0	90.0	-

Table 3-11. Stauffer Chemical-Montana Phosphorus Plant Feed Materials Characterization. (Continued)

Characteristic	Phosphate Ore	Coke	Silica
3. Radionuclide content, pCi/g(2)			
U-238	27	0.2	0.1
Th-230	39	0.3	0.5
Ra-226	26	0.1	0.2
Pb-210	38	0.5	0.6
Po-210	36	0.3	ND(3)
4. Feed material utilization, ton/ton P_4 produced(4)	10.1	1.3	1.4
5. Electrical power, kWh/short ton P_4 produced(4)	~12,000		

(1) Selected data obtained from Stauffer Chemical at November 9, 1982 meeting in Mt. Pleasant, Tennessee. Other data based on literature values of typical Montana silica and mid-western coke.

(2) Data from Ref. [21]

(3) ND = Not Detected

(4) SAI engineering estimates

sources and typical values for the composition, quantities used per short ton of phosphorus produced, and the radionuclide content for these feed materials. The range of values for the typical quantity reported is estimated as ± 10 percent.

3.3.2.4 Stauffer Chemical-Montana Plant Product Materials Characterization

The Stauffer Chemical-Montana plant produces the same basic products as described in Section 3.2. Table 3-12 provides the sales destination and typical values for the composition, quantities produced per short ton of elemental phosphorus produced, and the radionuclide content for these products. The range of values for the typical quantity reported is estimated as ± 10 percent.

3.3.2.5 Stauffer Chemical-Montana Plant Waste Materials

The Stauffer Chemical-Montana plant has a minor quantity of waste materials. Until about 1978, only the phossy water and sludge remained on site in appreciable quantities. Recently, Stauffer Chemical has been stockpiling the slag product awaiting Montana State resolution concerning its continued use as an aggregate rock material in roads, railroad beds, etc. The phossy water is recycled and the plant scrubber sludge residues are stored in clay-lined ponds awaiting a Stauffer Chemical decision on ultimate disposition.

Used furnace brick and scrap metal are decontaminated as necessary and sold for scrap at salvage value or reused in the process.

3.3.2.6 Stauffer Chemical-Montana Process Airborne Emissions and Sources Characterization

A key objective of this study was to identify and characterize the major airborne emission points. To fulfill this objective, plant operating permits at the Montana State Department of Health and Environmental Sciences in Helena, Montana, were obtained and a literature review was performed. The Stauffer Chemical-Montana plant was not toured, but key Stauffer Chemical staff members were interviewed November 9, 1982, at the Stauffer Chemical-Tennessee plant.

Table 3-12. Stauffer Chemical-Montana Phosphorus Plant Product Materials Characterization.

Characteristic	Phosphorus	Slag	Ferrophosphorus
1. Sales destination$^{(1)}$	Stauffer Chemical Plants	Stored on site	Local company
2. Utilization$^{(1)}$	Chemicals production	-	Vanadium metal recovery
3. Chemical composition, wt %$^{(1)}$			
SiO_2	-	$42^{(2)}$	-
CaO	-	$44^{(2)}$	-
Al_2O_3	-	$6^{(2)}$	-
Fe_2O_3	-	$0.4^{(2)}$	-
P_2O_5	-	$1.7^{(2)}$	-
P	>99.9	-	26
Fe	-	-	$56^{(2)}$
V	-	-	$7.0^{(2)}$
Cr	-	-	$6.0^{(2)}$

Table 3-12. Stauffer Chemical-Montana Phosphorus Plant Product Materials Characterization. (Continued)

Characteristic	Phosphorus	Slag	Ferrophosphorus
4. Radionuclide content, pCi/g(3)			
U-238	-	26	11
Th-230	-	50	0.5
Ra-226	0.02	30	0.4
Pb-210	0.3	0.5	0.7
Po-210	-	0.9	ND(4)
5. Production, ton/ton P_4 produced(1)	1.0	7.7	0.12

(1) Selected data obtained or calculated from information received from Stauffer Chemical at November 9, 1982, meeting in Mt. Pleasant, Tennessee.

(2) Assumed similar to other northwest plants.

(3) Ref. [21].

(4) ND = not detected.

Emission points were divided into point sources, vents, and fugitive sources. This section only reports emission sources and characterizes the emissions. The related air pollution control equipment is described in Chapter 4.

Point Sources

Table 3-13 lists the air pollution sources, emission points, and control equipment (characterized in Chapter 4). Point source emissions are generally continuous.

Vents

Table 3-14 lists the vents, including emergency vents, air pollution sources, emission points, and control equipment (characterized in Chapter 4). Vent emissions are intermittent.

Fugitive Sources

The fugitive emission sources are the slag pit, handling and stockpile areas; the plant roads; miscellaneous furnace leaks; and phosphate stockpile. Each of these areas is discussed below.

- Slag Pit, Handling, and Stockpile

  The slag pit and handling and stockpile areas are defined as fugitive emission sources. The molten slag tapped from the furnaces flows by gravity into a water-filled pit located adjacent to the furnace building. The cooled and fractured slag granules are recovered by front-end loaders and hauled by truck to the slag storage pile. The cooling, digging, hauling, and storage raises clouds of water vapor, dust, and P_2O_5 fumes. After drying, the stockpiled slag can also become a source of dust during high winds.

Table 3-13. Point Sources of Airborne Emissions For the Stauffer Chemical-Montana Plant

Air Pollution Source	Emission Points	Control Equipment
Enclosed ore handling system	Hooded transfer from feed pit to kiln feed bins to kilns vented via stack	Turbulaire wet scrubber
#1 rotary kiln, #1 nodule cooler and nodule sizing system	#1 kiln offgas scrubber stack #1 kiln nodule cooler/ sizing system stack	Multicyclone, spray tower, wet ESP Multicyclone, wet scrubber
#2 rotary kiln, #2 nodule cooler and nodule sizing system	#2 kiln offgas scrubber stack #2 kiln nodule cooler/ sizing system stack	Multicyclone, spray tower, wet ESP Multicyclone, wet scrubber
#1 kiln nodule ventilator	Kiln building ventilation and coke dryer stack	Turbulaire wet scrubber
#2 kiln nodule ventilator	Kiln building ventilation and coke dryer stack	Turbulaire wet scrubber
Proportioning building silo material handling	Proportioning building stack	Turbulaire wet scrubber
#1 and #2 electric furnaces	Phosphorus condenser stack	Each furnace has dry electrostatic precipitator followed by water spray condenser - condensers join flow to wet scrubber before stack venting
#1 and #2 electric furnaces slag and metal tapping	Taphole fume stack	Wet electrostatic precipitator standby venturi scrubber available
Roaster offgas condenser	Roaster offgas condenser stack	Wet scrubber

Table 3-14. Vents and Emergency Vents for the Stauffer Chemical-Montana Plant.

Air Pollution Source	Emission Points	Control Equipment
Furnace ESP explosion relief vents (ERV)	#1 furnace ERV	-
	#2 furnace ERV	-
Furnace pressure relief system (PRV)	#1 furnace PRV	-
	#2 furnace PRV	-
Elevated CO flare	#1 furnace CO flare	-
	#2 furnace CO flare	-
Kiln CO flare	#1 kiln CO flare	-
	#2 kiln CO flare	-

- Miscellaneous Furnace Leaks

  Each furnace has three carbon electrodes that are continuously fed into the furnace. To prevent furnace gas from leaking around the electrodes, they are equipped with Stauffer Chemical-designed seals. However, periodic pressure surges caused by bridging and collapse of material in the furnace allow gases to leak into the building.

- Plant Roads

  The plant roads are not paved and travel on these roads causes fugitive dust emissions.

- Ore Stockpile

  The ore stockpiles are not generally a problem because of the moisture content of the ore. However, during dry conditions, dust can be a problem from the stockpiles.

Key Sources of Radionuclide Emissions

The estimated annual particulate radionuclide emissions from the Stauffer Chemical-Montana plant are summarized in Table 3-15. The primary sources of emissions are the kiln stacks, which release about 9,000 pCi/s (0.28 Ci/yr) of Pb-210 and 6,400 pCi/s (0.2 Ci/yr) of Po-210. These results indicate that lead and polonium are volatilized by the rotary kiln process. The U-238, Th-230, and Ra-226 particulate emissions appear to be effectively removed by the multiple air cleaning systems that Stauffer Chemical uses in series on its kilns. About 8.2 Ci/yr of Rn-222 are also released from kiln operations at this plant.

Lead and polonium are also released from the furnaces, primarily during ferrophosphorus tapping [21]. Other relatively minor sources of particulate and volatilized emissions are the conveyer belt to the kiln feed bins, the nodule coolers, the coke dryer, and the feed proportioning silo collection dust system.

Table 3-15. Stack and Emission Data for the Stauffer Chemical-Montana Elemental Phosphorus Plant.

Source	Stack Geometry		Stack Gas Characteristics				Particulate Emissions		Radionuclide Emissions[1] pCi/s (Ci/yr)				
	Height (m)	Diameter (m)	Flow (ACMM)	Exit Velocity (m/s)	Exit Temperature C° (K°)	Heat Release (cal/s)	(g/m^3)	(g/s)	U-238	Th-230	Ra-226	Pb-210	Po-210
Ore belt transfer	12.2	0.9	1132	29.6	16 (289)	6.0×10^4	0.002	0.04	ND[2]	ND	0.6	5	8.4
Kiln #1	26.5	1.2	991	14.6	12 (285)	3.6×10^4	0.012	0.19	3.8	1.9	5.5	4500	3200
Kiln #2[3]	26.5	1.2	991	14.6	10 (283)	2.6×10^4	0.013	0.21	3.8	1.9	5.5	4500	3200
Nodule cooler #1	24.4	1.8	1415	9.3	38 (311)	2.2×10^5	0.022	0.37	0.30	0.84	3.3	7.5	50
Nodule cooler #2[4]	24.4	1.8	1415	9.3	38 (311)	2.2×10^5	0.024	0.39	0.30	0.84	3.3	7.5	50
#1 Kiln ventilator[5]	24.4	1.8	1698	11.6	24 (297)	1.6×10^5	0.005	0.15	9.8	19	17	18	ND
#2 Kiln ventilator[5]	24.4	1.8	1698	11.6	24 (297)	1.6×10^5	0.012	0.35	9.8	19	17	18	ND
Silo duct	12.2	1.2	566	8.3	13 (286)	2.2×10^4	0.012	0.11	0.89	2.3	4.8	10	ND
Furnace tapholes	12.2	1.2	1132	16.7	10 (283)	2.9×10^4	0.052	0.98	ND	ND	ND	43	85
Condenser[6]	12.2	0.9	708	18.5	24 (297)	6.5×10^4	0.011		Not Estimable				
Roaster[6]	10.4	0.5	113	9.6	46 (319)	1.3×10^3	0.002						
Totals									29 (0.001)	46 (0.0015)	57 (0.0018)	9100 (0.29)	6600 (0.21)

(1) All data from Ref. [21] unless otherwise noted.

(2) ND = Not detected

(3) Assumes Kiln #2 discharges same as Kiln #1; also, a total of 8.2 Ci/yr Ra-222 is released from kiln operations.

(4) Assumes Nodule Cooler #2 discharges same as Nodule Cooler #1.

(5) Assumes Coke Dryer emissions are each equal to Kiln Ventilator emissions reported in Ref. [21].

(6) Particulate emissions from these sources probably consist mostly of P_2O_5 fumes.

The ore stockpile at the Stauffer Chemical-Montana plant has an average surface area of 38,800 m^2. Assuming an average radon emanation rate of 120 pCi/m^2-min [22], about 2.5 Ci/yr of Rn-222 would be released from this source. The slag pile has a considerably greater surface area (188,800 m^2) than the ore stockpile, but releases only about 0.35 Ci/yr because of the much lower radon emanation rate characteristic of the slag matrix [22].

Activity Balance

The flow of radioactivity through the Stauffer Chemical-Montana plant is illustrated in Figure 3-10. The data indicate that only 70 to 80 percent of the input U-238 and Ra-226 and less than 90 percent of the input Th-230 are accounted for in the slag. Well over 90 percent of the input Pb-210 and Po-210 is released during phosphorus production, and most of this material is probably contained in scrubber effluents released to the liquid settling ponds. Significant amounts of U-238, Th-230, and Ra-226 (3.3, 1.8, and 2.1 Ci, respectively) are also deposited in the settling ponds.

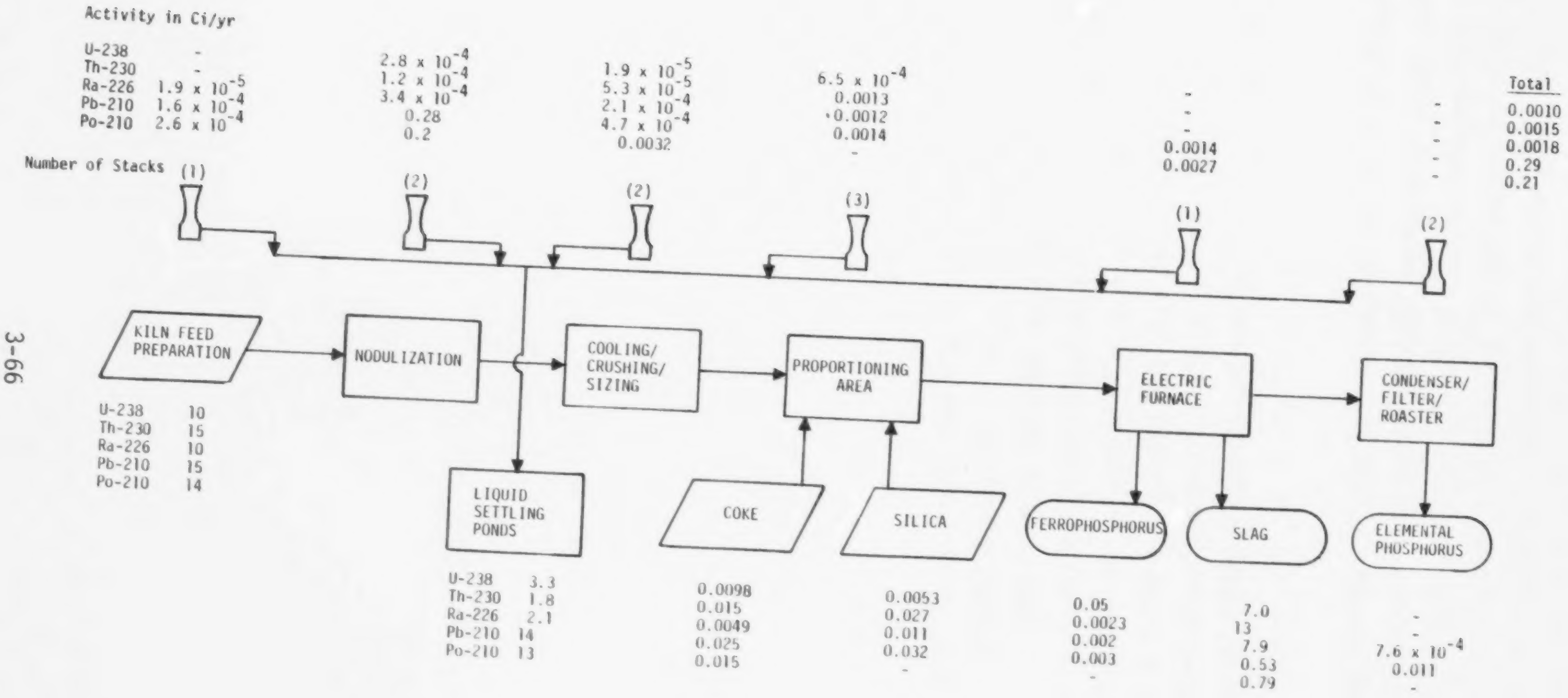

Activity in Ci/yr
U-238 -
Th-230 -
Ra-226 1.9×10^{-5}
Pb-210 1.6×10^{-4}
Po-210 2.6×10^{-4}
Number of Stacks (1)
2.8×10^{-4}
1.2×10^{-4}
3.4×10^{-4}
0.28
0.2
(2)
1.9×10^{-5}
5.3×10^{-5}
2.1×10^{-4}
4.7×10^{-4}
0.0032
(2)
6.5×10^{-4}
0.0013
0.0012
0.0014
-
(3)
-
-
-
0.0014
0.0027
(1)
-
-
-
-
-
(2)
Total
0.0010
0.0015
0.0018
0.29
0.21
KILN FEED PREPARATION
U-238 10
Th-230 15
Ra-226 10
Pb-210 15
Po-210 14
NODULIZATION
COOLING/ CRUSHING/ SIZING
LIQUID SETTLING PONDS
U-238 3.3
Th-230 1.8
Ra-226 2.1
Pb-210 14
Po-210 13
PROPORTIONING AREA
COKE
0.0098
0.015
0.0049
0.025
0.015
SILICA
0.0053
0.027
0.011
0.032
-
ELECTRIC FURNACE
FERROPHOSPHORUS
0.05
0.0023
0.002
0.003
-
SLAG
7.0
13
7.9
0.53
0.79
CONDENSER/ FILTER/ ROASTER
ELEMENTAL PHOSPHORUS
-
-
7.6×10^{-4}
0.011
-

Figure 3-10. Activity Balance for the Stauffer Chemical-Montana Plant.

3.3.3 Stauffer Chemical Plant - Mt. Pleasant, Tennessee

3.3.3.1 Stauffer Chemical-Tennessee Plant Site Characterization

The Stauffer Chemical-Tennessee plant is located 2.4 km southwest of the town of Mount Pleasant at 87° 14' 0" longitude and 35° 31' 0" latitude and at an elevation of about 213 m. Located on the Big Bigsby Creek, the plant is separated by an access road from strip mines to the south and is near railroad lines, with spurs servicing the plant. The plant is in an area of small rolling hills and scattered woodlands. Large areas of currently used and reclaimed strip mines and tailing ponds are east of the plant and town. A map indicating the general area and major features is shown in Figure 3-11.

Meteorology and Air Quality

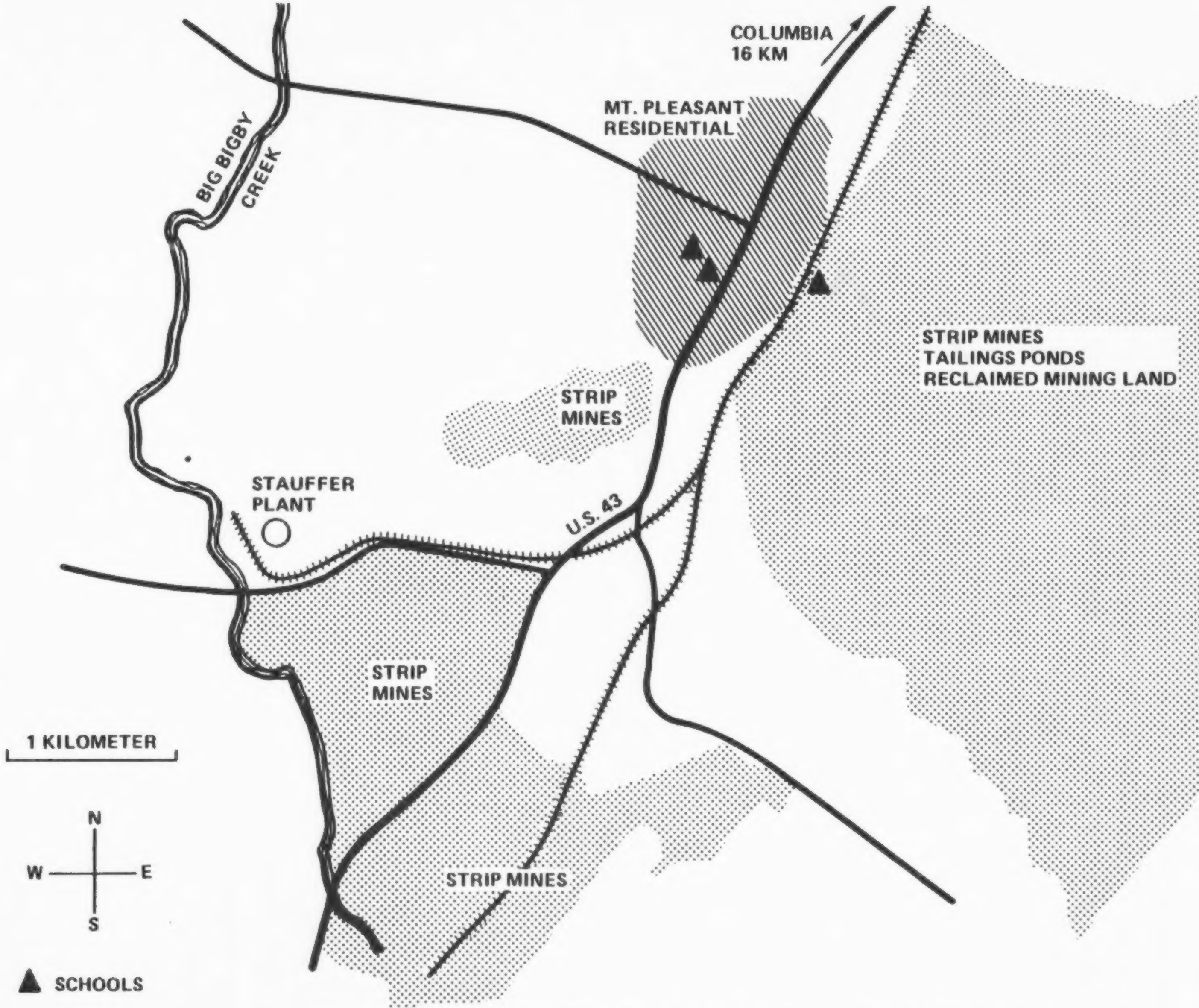
Annual rainfall for the area averages 140 cm and the annual average temperature is 13.8°C. Winds are generally from the southwest at 2 to 3 m/s.

Demography

The plant is in Maury County, which had a population of 51,085, or about 32 persons per km^2, as of the 1980 census. Actual population densities surrounding the plant are given in Appendix A.

Land Use

Seventy-five percent of the county is farmland. Produce and food grains are raised on approximately one percent of the land in the county, with 63 percent of the farmland used to produce animal feed. Beef cattle, milk cows, hogs, sheep, turkeys, chickens, and laying hens are all raised in the county. Hogs are raised in approximately the same numbers as beef cattle. These two animals account for 90 percent of the meat production in the county. About 2 percent of the county land is used for agricultural ponds.



COLUMBIA
16 KM
MT. PLEASANT
RESIDENTIAL
BIG BIGBY
CREEK
STRIP MINES
TAILINGS PONDS
RECLAIMED MINING LAND
STRIP
MINES
STAUFFER
PLANT
U.S. 43
STRIP
MINES
1 KILOMETER
N
W
E
S
STRIP MINES
▲ SCHOOLS

Figure 3-11. Stauffer Chemical-Tennessee Plant Site Area.

3.3.3.2 The Stauffer Chemical-Tennessee Process

Phosphate ore from the Globe Mine in Tennessee is shipped to the plant by truck. Ore is shipped continuously throughout the year, and an ore stockpile is maintained on site. The plant operates 24 hours per day, 365 days per year. A schematic of plant operations is provided as Figure 3-12.

The ore cars are emptied into a pit from which hooded conveyer belts transfer the ore to either of two large stockpiles. The process of ore blending is initiated here by the layering of the ore as it is stockpiled. Ore is removed from one stockpile while the other stockile is being accumulated. The ore is further blended during ore removal by front-end loaders. The front-end loaders deliver the ore to a transfer pit where hooded belt conveyers move it to feed hoppers in the kiln feed building. The kiln-specific feed hoppers include fines recycle feed hoppers (coke dust, nodule and ore transfer dust) and provide blended feed ore and recycle dust to the two rotary kilns by hooded belt conveyer feeders. Only one of two existing kilns is currently used.

The rotary kilns produce large, stable agglomerates (nodules), which are required for proper operation of the electric reduction furnaces. The rotary kilns heat the ore to its incipient melting point (about 1300°C), and the tumbling action causes the ore to agglomerate into the desired nodular form. The rotary kilns are fueled with carbon monoxide generated in the electric reduction furnace operation. The kiln offgas is vented into kiln-specific and identical offgas treatment operations consisting of Buell cyclones and a spray scrubbing tower. The wet scrubber uses a lime scrubbing liquor to remove fluorine, SO_2, and particulates. The hot nodules are passed through kiln-specific processing sequences of nodule cooling, crushing, and screening. The appropriately-sized nodular material is sent to nodule storage and the fines are sent to the nodule fines roasters. The offgas stream from each nodule cooler is treated by a separate spray tower. Offgases from nodule crushing/sizing operations are treated by separate wet scrubbers.

The nodule fines roasters are rotary kilns that also receive the sludge resulting from the product phosphorus filtering operation. The nodule fines and sludge roasting operations are used to recover residual phosphorus. The roaster offgases are treated with a single condenser.

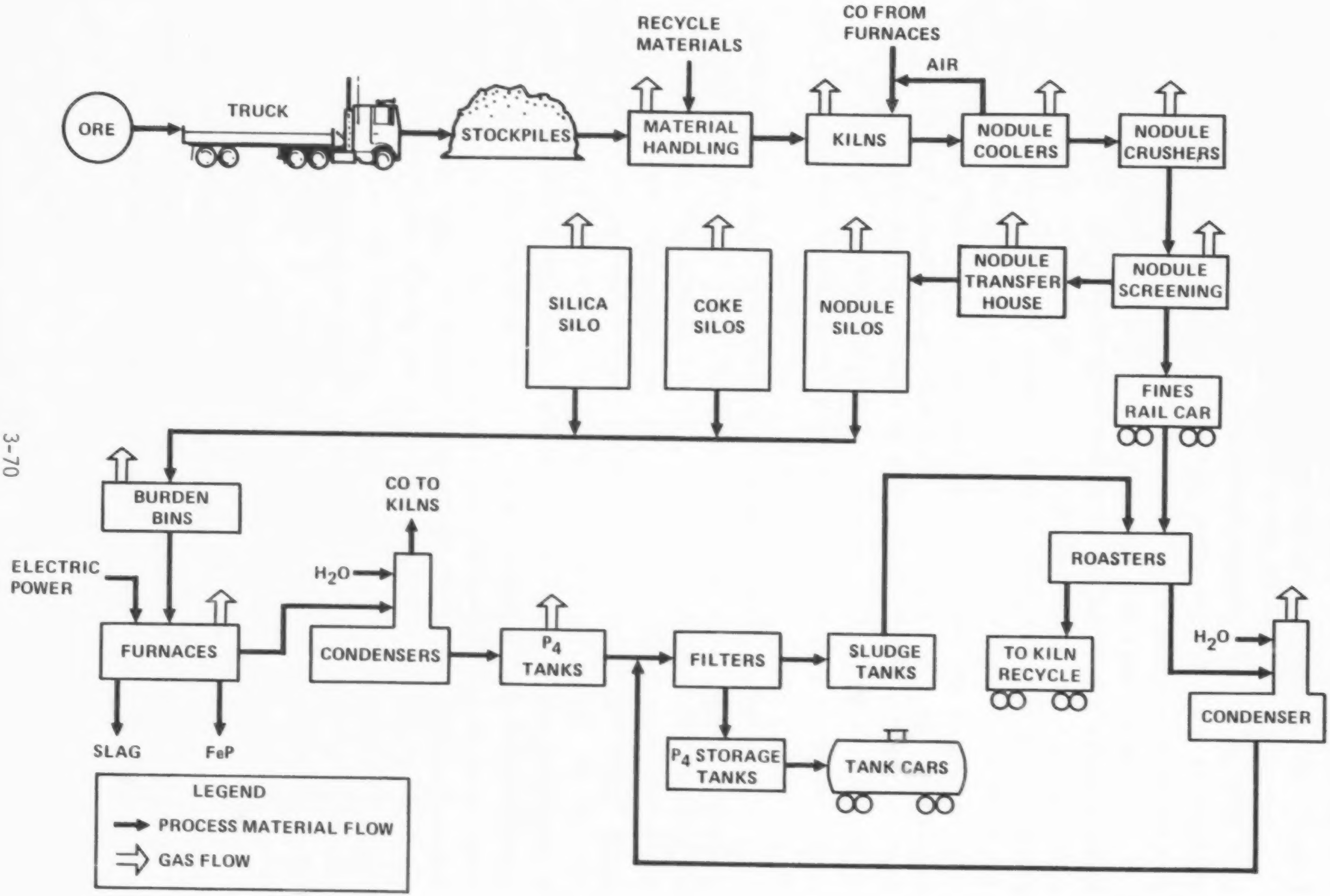

ORE
TRUCK
STOCKPILES
RECYCLE MATERIALS
MATERIAL HANDLING
CO FROM FURNACES
AIR
KILNS
NODULE COOLERS
NODULE CRUSHERS
NODULE SCREENING
NODULE TRANSFER HOUSE
SILICA SILO
COKE SILOS
NODULE SILOS
FINES RAIL CAR
BURDEN BINS
ELECTRIC POWER
FURNACES
SLAG
FeP
CO TO KILNS
H_2O
CONDENSERS
P_4 TANKS
FILTERS
SLUDGE TANKS
ROASTERS
TO KILN RECYCLE
H_2O
CONDENSER
P_4 STORAGE TANKS
TANK CARS
LEGEND
PROCESS MATERIAL FLOW
GAS FLOW

Figure 3-12. Simplified Process Flow Diagram for the Stauffer Chemical-Tennessee Plant.

Following the sizing operation, the nodular material is sent to the proportioning building where it is stored in one of seven nodule storage silos. Metallurgical grade coke is sized on site and stored in one of three coke storage silos in the proportioning building. Locally mined silica is stored in the silica storage silo. The nodules, coke, and silica are mixed using a proportioning weighing system. This furnace burden is moved by hooded belt conveyer to a skip hoist that loads the material into the elevated burden bins. The enclosed burden bins are located above the furnaces and continuously feed the furnaces by gravity.

Stauffer Chemical operates four electric reduction furnaces at this plant. Operating temperatures range from 1400 to 1800°C. The furnaces operate continuously and are periodically tapped to remove the molten slag and ferrophosphorus that accumulates at the bottom. Slag taps occur approximately every 1.5 hours for 15 to 45 minutes and ferrophosphorus taps occur approximately every 8 hours for about 20 minutes. The slag flows into a pit adjacent to the furnace building. Water sprays are used to cool and fracture the slag. The cooled slag is loaded into trucks by a front-end loader and hauled to a stockpile. The ferrophosphorus is chilled, crushed and sold to metal processors.

The furnace offgases, composed of mainly carbon monoxide and phosphorus, are drawn through furnace-specific treatment systems. First, the furnace offgas is sent to a condenser where the gases are cooled and the phosphorus condenses. The CO is then either routed to the rotary kilns and burned or flared to the atmosphere. The condensed phosphorus is collected in tanks, filtered, and displaced to underwater storage. The stored phosphorus is top loaded into water-sealed railroad cars for shipment to Stauffer Chemical plants where it is combined with other elements to make various phosphate compounds.

3.3.3.3 Stauffer-Tennessee Plant Feed Materials Characterization

The Stauffer-Tennessee plant utilizes the same feed materials as the basic process plant described in Section 3.2. These include phosphate ore, coke and silica. Table 3-16 provides a summary description of these raw materials including sources, selected compositional information, quantities used per short ton of phosphorus produced, and the radionuclide content

Table 3-16. Stauffer Chemical-Tennessee Phosphorus Plant Feed Materials Characterization.

Characteristic	Phosphate Ore	Coke	Silica
1. Source	Globe Mine, Tennessee	Southeastern Supplier	Mined in local creek beds
2. Chemical Composition, wt%(1)			
P_2O_5	26.5	-	-
SiO_2	16.0	3.3(2)	97
CaO	36.5	-	0.25(2)
Al_2O_3	3.5	1.3(2)	1.5(2)
Fe_2O_3	6.0	0.3(2)	1.0(2)
C	-	>85	-

Table 3-16. Stauffer Chemical-Tennessee Phosphorus Plant Feed Materials Characterization. (Continued)

Characteristic	Phosphate Ore	Coke	Silica
3. Radionuclide Content, pCi/g(2)			
U-238	3.0(3)	0.4	0.3
Th-230	3.0(3)	0.6	1.1
Ra-226	4.0(3)	0.5	0.4
Pb-210	4.2(3)	0.9	1.0
Po-210	3.5(3)	0.8	0.8
4. Feed material Utilization, ton/ton P_4 produced(4)	10.7	1.6	1.7
5. Electrical power, kWh/short ton P_4 produced(2)	- 13,000 -		

(1) Typical values for Tennessee phosphate ores. Assumed same as Occidental Chemical Corporation phosphorus plant feed materials.

(2) Data presented to SAI staff at November 9, 1982, meeting at Stauffer Chemical's Elemental Phosphorus Plant at Mt. Pleasant, TN.

(3) Data from Ref. [22].

(4) SAI engineering estimate.

of these feed materials. The range of values for the typical quantity reported is estimated as ±10 percent.

3.3.3.4 Stauffer Chemical-Tennessee Plant Product Materials Characterization

The Stauffer Chemical-Tennessee plant produces the same basic products as described in Section 3.2. Table 3-17 provides the sales destination and typical values for the composition, quantities produced per short ton of elemental phosphorus produced, and the radionuclide content of the products. The range of values for the typical quantity reported is estimated as ±10 percent.

3.3.3.5 Stauffer Chemical-Tennessee Plant Waste Materials

The Stauffer Chemical-Tennessee plant has only a minor quantity of waste materials. Only the phossy water and sludge remain on site in appreciable quantities. The phossy water is recycled, and the plant scrubber sludge residues are stored in plastic-lined ponds awaiting a decision concerning ultimate disposition.

Used furnace brick is reprocessed, and scrap metal is decontaminated as necessary and sold for scrap at salvage value.

3.3.3.6 Stauffer Chemical-Tennessee Process Airborne Emissions and Sources Characterization

A key objective of this study was to identify and characterize the major airborne emissions points. To fulfill this objective, plant operating permits at the Tennessee State Department of Public Health, Air Pollution Control Division, in Nashville, Tennessee, were obtained and a literature review was conducted. In addition, the plant was toured on November 9, 1982, and key staff members were interviewed.

Emission points were divided into point sources, vents, and fugitive sources. This section only reports emission sources and characterizes the emissions. The related air pollution control equipment is described in Chapter 4.

Table 3-17. Stauffer Chemical-Tennessee Phosphorus Plant Product Materials Characterization.

Characteristic	Phosphorus	Slag	Ferrophosphorus
1. Sales Destination(1)	Stauffer Chemical plants	Sold and stored on site	Sold to steel industry
2. Utilization(1)	Chemicals production	Railroad ballast and road beds	Metal coatings additive
3. Chemical Composition, wt%(2)			
SiO_2	-	44	
CaO	-	47	
Al_2O_3	-	5.5	
P_2O_5	-	1.5	
P	>99.9	-	23
Fe	-	-	70
V	-	-	3.0
Cr	-	-	0.25

Table 3-17. Stauffer Chemical-Tennessee Phosphorus Plant Product Materials Characterization. (Continued)

Characteristic	Phosphorus	Slag	Ferrophosphorus
4. Radionuclide content, pCi/g(1)			
U-238	-	2.4	1.1
Th-230	-	4.2	0.05
Ra-226	-	3.2	0.05
Pb-210	-	0.3	0.1
Po-210	-	0.4	0.05
5. Production ton/ton P_4 produced(3)	1.0	7.5	0.27

(1) Data presented to SAI staff at November 9, 1982, meeting at Stauffer Chemical's Elemental Phosphorus Plant in Mt. Pleasant, TN.

(2) Data assumed to be identical to that for Occidental Chemical Plant.

(3) SAI engineering estimates.

Point Sources

Table 3-18 presents a listing of the air pollution sources, emission points and control equipment (characterized in Chapter 4). Point source emissions are generally continuous.

Vents

Table 3-19 lists the vents, including emergency vents, air pollution sources, emission points, and control equipment (characterized in Chapter 4). Vent emissions are intermittent.

Fugitive Sources

The fugitive emission sources are the slag pit, handling and stockpile areas; plant roads; miscellaneous furnace leaks; and the phosphate stockpile. Each of these areas is discussed below.

- Slag Pit, Handling and Stockpile
  The slag pit, handling and interim stockpiles are defined as fugitive emission sources. The molten slag tapped from the furnaces flows by gravity into a water-filled pit located adjacent to the furnace building. The cooled and fractured slag granules are recovered by front-end loaders and hauled by truck to the slag storage pile. The cooling, digging and hauling, and storage raises minor amounts of water vapor, dust and P_2O_5 fumes. After drying, the interim stockpile of slag can also become a minor source of dust during high winds.

- Miscellaneous Furnace Leaks
  Each furnace has three carbon electrodes that are continuously fed into the furnace. To prevent furnace gas from leaking around the electrodes, they are equipped with Stauffer-designed seals. However, periodic pressure surges caused by bridging and collapse of material in the furnace allow gases to leak into the building.

- Plant Roads
  The plant roads are paved and travel on these roads causes only minor fugitive dust emissions.

Table 3-18. Point Sources of Airborne Emissions for the Stauffer Chemical-Tennessee Plant.

Air Pollution Source	Emission Points	Control Equipment
#1 rotary kiln and nodule cooler(1)	#1 kiln scrubber stack	Cyclone, spray tower scrubber
	#1 kiln nodule cooler stack	Spray tower scrubber
#2 rotary kiln and nodule cooler	#2 kiln scrubber stack	Cyclone, spray tower scrubber
	#2 kiln nodule cooler stack	Spray tower scrubber
#2 rotary kiln nodule crushing/sizing system	#2 kiln nodule crushing/sizing stack	Spray tower scrubber
	#2 kiln fines removal screener stack	Turbulaire scrubber
Lime storage silo	Lime storage silo stack	Baghouse
Nodule transfer house	Nodule transfer stack	Turbulaire scrubber
Proportioning building	Proportioning building stacks (two)	Turbulaire scrubbers (two)
Feed storage silos	Silica and nodule handling system stack	Turbulaire scrubber
Coke drying, sizing and handling(1)	Coke system stack	Turbulaire scrubber
Skip hoist operation	Skip hoist system stack	Turbulaire scrubber
Electric furnaces	Phosphorus condenser stacks (four)	Each furnace offgas (#3 & #4 combined) has water spray condenser followed by spray tower and demister before stack venting

(1) Inactive

Table 3-18. Point Sources of Airborne Emissions for the Chemical-Tennessee Plant. (Continued)

Air Pollution Source	Emission Points	Control Equipment
Electric furnaces slag and ferrophosphorus tapping	Taphole fume stacks (three)	Each furnace system has venturi scrubber and cyclone separator (#3 & #4 combined)
Roaster offgas condensers	#1 roaster offgas condenser stack	Water spray condenser
	#3 roaster offgas condenser stack	Water spray condenser

Table 3-19. Vents and Emergency Vents for the Stauffer Chemical-Tennessee Plant.

Air Pollution Sources	Emission Points	Control Equipment
Furnace ESP explosion relief vents (ERV)	#1 furnace ERV	-
	#2 furnace ERV	-
	#3 furnace ERV	-
	#4 furnace ERV	-
	#5 furnace ERV	-
Furnace pressure relief system (PRV)	#1 furnace PRV	-
	#2 furnace PRV	-
	#3 furnace PRV	-
	#4 furnace PRV	-
	#5 furnace PRV	-
Elevated CO flares	#1 furnace CO flare	-
	#2 furnace CO flare	-
	#3 furnace CO flare	-
	#4 furnace CO flare	-
	#5 furnace CO flare	
Kiln CO flares	#1 kiln CO flare(1)	-
	#2 kiln CO flare	-

(1) inactive

- Ore Stockpile

  The ore stockpile is not generally a problem because of the moisture content of the ore. However, during dry conditions, dust can be a problem from the stockpile.

Key Sources of Radionuclide Emissions

The estimated annual particulate radionuclide emissions from the Stauffer Chemical-Tennessee plant are summarized in Table 3-20. Essentially all the volatile radionuclide releases occur from the kiln stacks, with cumulative releases from two kilns totaling 1180 pCi/s (0.037 Ci/yr) of Pb-210 and 730 pCi/s (0.023 Ci/yr) of Po-210. Only minor amounts of particulate radioactivity are released, with the principal sources of these emissions being the kiln cooler stacks, the nodule screening and transfer house stacks, the nodule fines storage area stack, and the CO flare.

No data are available on Rn-222 releases from the Stauffer Chemical-Tennessee process. However, this release was estimated at 1.2 Ci/yr using the Rn-222 release data from the Stauffer Chemical-Montana plant in conjunction with differences in quantities of Ra-226 processed annually.

The surface area of the Stauffer Chemical-Tennessee ore stockpile averages about 8,400 m^2. Assuming an average radon emanation rate of about 18 pCi/m^2-min [22], an estimated 0.08 Ci/yr is released. The slag stockpile is much larger (45,000 m^2) than the ore stockpile but has a much lower emanation rate (0.05 pCi/m^2-min). Thus, the estimated Rn-222 release rate from the slag stockpile is 0.012 Ci/yr [22].

Activity Balance

The flow of radioactivity through the Stauffer Chemical-Tennessee plant is illustrated in Figure 3-13. Much of the input U-238, Th-230, and Ra-226 can be accounted for in the output slag material (approximately 55, 90, and 55 percent, respectively), but virtually all the Pb-210 and Po-210 are released during the phosphorus production process. Over 90 percent of the input Pb-210 and Po-210 is unaccounted for in plant products. On the basis of effluent air samples from the Stauffer Chemical-Montana plant [22], these materials are not likely to be emitted in gaseous effluents. Presum-

Table 3-20. Stack and Emission Data for the Stauffer Chemical-Tennessee Elemental Phosphorus Plant.

Source	Stack Geometry		Stack Gas Characteristics				Particulate Emissions		Radionuclide Emissions pCi/s (Ci/yr)				
	Height (m)	Diameter (m)	Flow (ACMM)	Exit Velocity (m/s)	Exit Temperature C° (K°)	Heat Release (cal/s)	(g/m^3)	(g/s)	U-238	Th-230	Ra-226	Pb-210	Po-210
#1 kiln(1)	35.4	9.1	1561	0.4	68 (341)	3.6×10^5	0.043	1.13	3.4	3.4	4.5	360	220
#1 kiln cooler(2)	12.5	1.5	1537	14.5	50 (323)	2.6×10^5	0.022	0.57	2.0	1.7	2.2	1.6	2.0
Lime baghouse	12.2	0.3	14	3.4	21 (294)	5.4×10^2	0.129	0.03	------- Negligible Radioactivty --------				
#2 kiln(1)	33.5	13.7	3538	0.4	68 (341)	8.2×10^5	0.004	2.61	7.8	7.8	10	820	510
CO booster fan tank vent(2)	47.2	0.6	58	3.4	609 (882)	1.4×10^5	0.207	0.20	11	9.3	12	8.7	11
CO flare(2)	27.4	0.5	161	13.7	609 (882)	1.4×10^5	1.081	2.90					
#2 kiln cooler(2)	18.0	2.1	2701	13.0	44 (317)	3.9×10^5	0.015	0.68	2.4	2.0	2.6	1.9	2.4
#2 kiln crusher/ screen(2)	18.0	1.3	1155	14.5	40 (313)	1.4×10^5	0.031	0.60	2.1	1.8	2.3	1.7	2.1
Nodule transfer screen(2)	4.9	0.8	353	11.7	32 (305)	2.9×10^4	0.036	0.21	3.3	2.9	3.6	2.7	3.3
Nodule screen/fines storage(2)	9.1	0.1	19	22.5	27 (300)	1.4×10^3	0.382	0.07					
Nodule transfer house(2)	12.3	0.7	265	13.0	34 (307)	2.4×10^4	0.134	0.67					
#3 roaster/condenser	11.6	0.1	1	2.3	21 (294)	27	45.6	0.76	------- Negligible Radioactivity --------				
#1 roaster/condenser	10.1	0.1	1	2.3	21 (294)	27	11.4	0.19					
Condenser stack #2	33.5	0.5	20	1.7	52 (325)	2.5×10^3	0.30	0.10					
Condenser stack #3	33.5	0.5	20	1.7	52 (325)	2.5×10^3	0.30	0.10					
Condenser stack #4	33.5	0.5	20	1.7	52 (325)	2.5×10^3	0.30	0.10					
Condenser stack #5	30.8	1.5	21	0.2	52 (325)	2.5×10^3	0.30	0.10					
Silos transfer	12.5	0.7	480	20.8	21 (204)	1.8×10^4	-	-	------------ Not Estimable ------------				

Table 3-20. Stack and Emission Data for the Stauffer Chemical-Tennessee Elemental Phosphorus Plant. (Continued)

Source	Stack Geometry		Stack Gas Characteristics				Particulate Emissions		Radionuclide Emissions pCi/s (Ci/yr)				
	Height (m)	Diameter (m)	Flow (ACMM)	Exit Velocity (m/s)	Exit Temperature C° (K°)	Heat Release (cal/s)	(g/m^3)	(g/s)	U-238	Th-230	Ra-226	Pb-210	Po-210
Coke dryer(3)	12.2	1.1	826	14.5	54 (327)	1.4×10^5	0.024	0.33	0.02	0.07	0.26	0.02	0.02
Silo collector(4)	12.2	0.9	492	12.9	21 (294)	1.8×10^4	0.017	0.14	0.38	0.36	0.42	0.39	0.49
#5 furnace building top prop. area(4)	12.5	0.5	92	7.8	40 (313)	1.2×10^4	0.039	0.06	0.16	0.14	0.18	0.17	0.21
#5 furnace tapholes	10.1	0.8	648	21.5	57 (323)	9.8×10^4	0.008	0.09	-	-	-	-	-
Old furnace building top prop. area(4)	12.5	0.6	180	10.6	22 (295)	7.9×10^3	0.007	0.02	0.05	0.05	0.06	0.06	0.07
#2 furnace tapholes	14.9	1.0	565	12.0	49 (321)	8.1×10^4	0.005	0.05	-	-	-	0.19	0.16
FeP crusher/screen	4.9	0.4	99	13.1	49 (322)	1.4×10^4	0.194	0.32	-	-	-	1.2	1.0
#3 & #4 furnace tapholes	30.0	1.0	565	12.0	49 (322)	8.1×10^4	0.011	0.10	-	-	-	0.38	0.32
Totals									33 (0.001)	30 (9.3×10^{-4})	38 (0.0012)	1200 (0.038)	750 (0.024)

(1) Assumes radionuclide concentrations of particulate emissions same as that of PO_4 ore for U-238, Th-230, and Ra-226; for Pb-210 and Po-210 emissions, estimates are based on Stauffer Chemical-MT kiln emissions factored by differences in radionuclide concentrations in ore and ore process rates.

(2) Assumes radionuclide concentrations of particulate emissions same as that of nodules.

(3) Assumes radionuclide concentrations of particulate emissions same as that of coke.

(4) Assumes that particulate emissions consist of 75 percent nodule material, 10 percent coke, and 15 percent silica.

(5) Assumes that particulate emissions consist mainly of P_2O_5 with a Pb-210 content of 3 pCi/g and Po-210 content of 3.2 pCi/g.

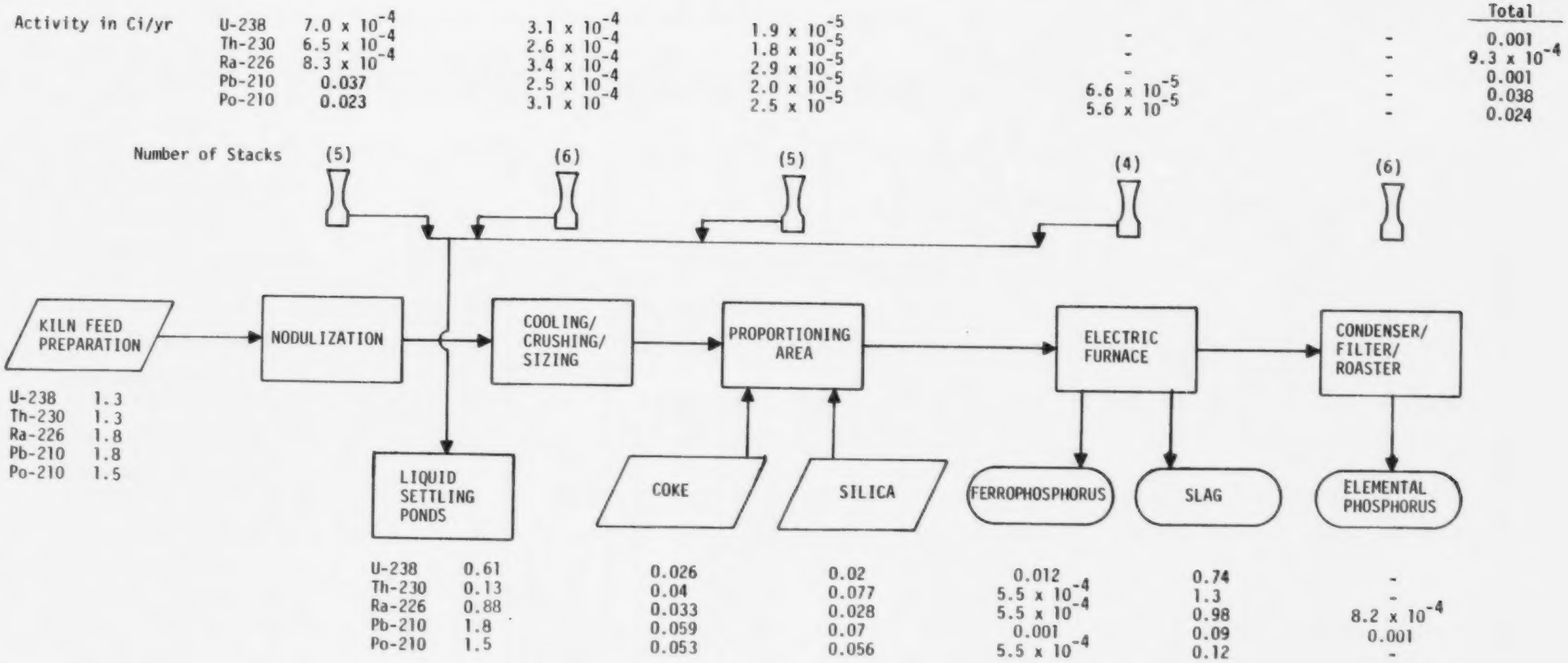

Activity in Ci/yr
U-238 7.0×10^{-4}
Th-230 6.5×10^{-4}
Ra-226 8.3×10^{-4}
Pb-210 0.037
Po-210 0.023
3.1×10^{-4}
2.6×10^{-4}
3.4×10^{-4}
2.5×10^{-4}
3.1×10^{-4}
1.9×10^{-5}
1.8×10^{-5}
2.9×10^{-5}
2.0×10^{-5}
2.5×10^{-5}
-
-
-
6.6×10^{-5}
5.6×10^{-5}
-
-
-
-
-
Total
0.001
9.3×10^{-4}
0.001
0.038
0.024
Number of Stacks
(5)
(6)
(5)
(4)
(6)
KILN FEED PREPARATION
U-238 1.3
Th-230 1.3
Ra-226 1.8
Pb-210 1.8
Po-210 1.5
NODULIZATION
COOLING/ CRUSHING/ SIZING
PROPORTIONING AREA
ELECTRIC FURNACE
CONDENSER/ FILTER/ ROASTER
LIQUID SETTLING PONDS
U-238 0.61
Th-230 0.13
Ra-226 0.88
Pb-210 1.8
Po-210 1.5
COKE
0.026
0.04
0.033
0.059
0.053
SILICA
0.02
0.077
0.028
0.07
0.056
FERROPHOSPHORUS
0.012
5.5×10^{-4}
5.5×10^{-4}
0.001
5.5×10^{-4}
SLAG
0.74
1.3
0.98
0.09
0.12
ELEMENTAL PHOSPHORUS
-
-
8.2×10^{-4}
0.001
-

Figure 3-13. Activity Balance for the Stauffer Chemical-Tennessee Plant.

ably, most of the volatilized Pb-210 and Po-210 is condensed by the kiln spray tower water and transported to the settling ponds. The ferrophosphorus and elemental phosphorus products contain dilute but measurable quantities of radionuclides.

3.3.4 Stauffer Chemical Plant - Tarpon Springs, Florida

The Stauffer Chemical-Florida plant is currently on standby status awaiting an increase in the demand for phosphorus. No projected restart date is available.

3.3.4.1 Stauffer Chemical-Florida Plant Site Characterization

The Stauffer Chemical-Florida plant is located at 28° 10' 30" latitude and 82° 47' 0" longitude at sea level on the west coast of central Florida. The plant is 3 km northwest from the town of Tarpon Springs and 48 km north of the Tampa Bay metropolitan area. The plant is 2 km inland and 6 km east of the Anclote Keys Special State Conservation Area on the Anclote River at Meyer's Cove. It is near railroad lines, with spurs servicing the plant. High density residential areas exist in all inland directions around the plant. Underdeveloped areas around the plant are primarily wetlands and sand dunes. A map indicating the general area and major features is shown in Figure 3-14.

Meteorology and Air Quality

Rainfall averages 185 cm annually and the average annual temperature is 22°C. Winds in the area are primarily from the west at 2 to 5 m/s. The plant is not in a non-attainment area for particulates. However, the plant is in the area of influence of the non-attainment area of primary National Ambient Air Quality Standards for particulates in adjacent Hillsborough County. It is the plant's opinion that it does not influence that area to any measurable extent.

Demography

The plant is located in Pinellas County, which had a population of 728,531, or 1073 persons per km^2 as of the 1980 census. Actual population distributions around the plant are given in Appendix A.

Land Use

Nine percent of the county is farmland of which 58 percent is used for food production. Only protected produce (primarily citrus) and food grains are produced commercially. Livestock and poultry are raised in

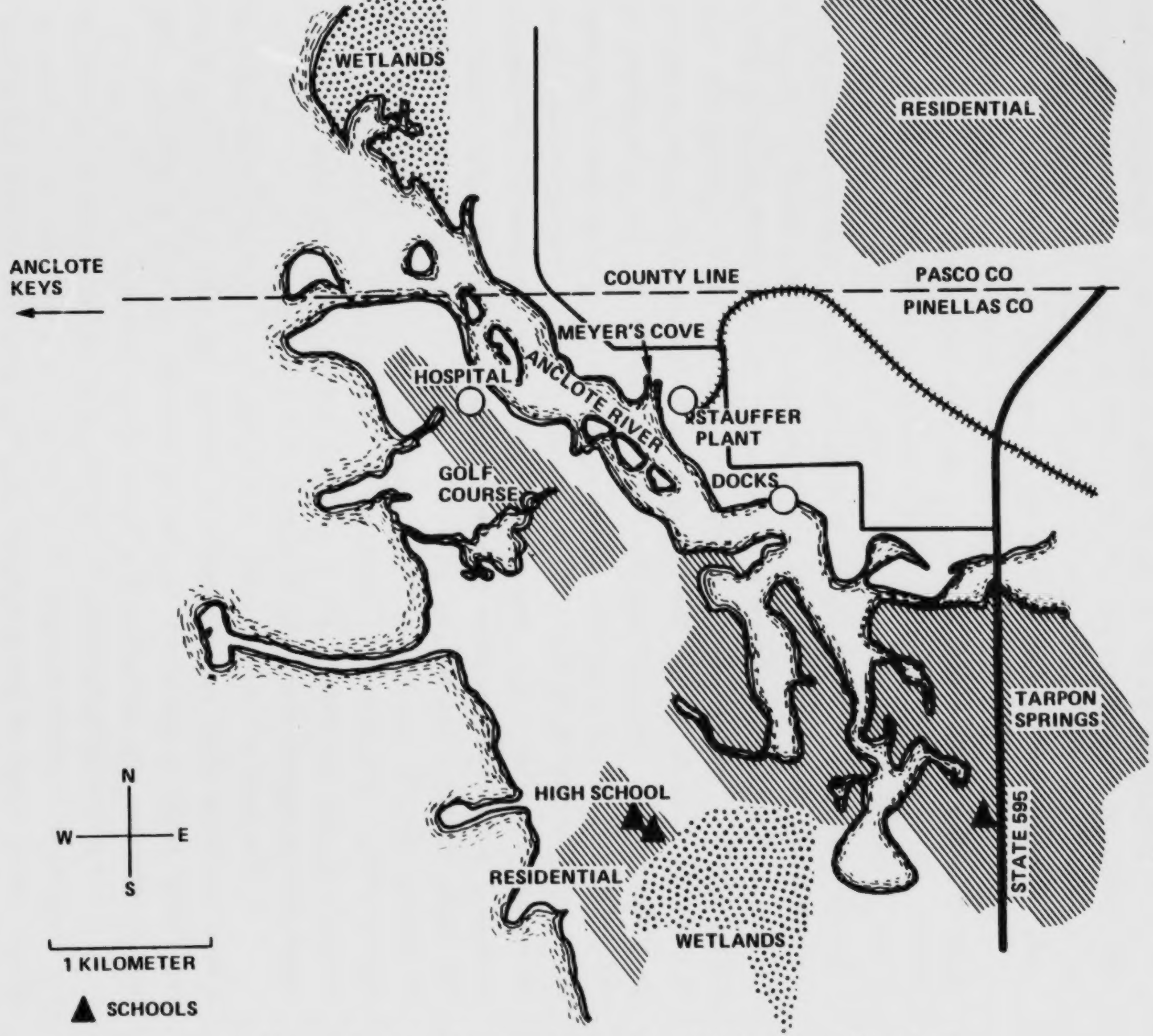

WETLANDS
RESIDENTIAL
ANCLOTE KEYS
COUNTY LINE
PASCO CO
PINELLAS CO
MEYER'S COVE
HOSPITAL
ANCLOTE RIVER
STAUFFER PLANT
DOCKS
GOLF COURSE
TARPON SPRINGS
HIGH SCHOOL
RESIDENTIAL
WETLANDS
STATE 595
N
W
E
S
1 KILOMETER
SCHOOLS

Figure 3-14. Stauffer Chemical-Florida Plant Site Area.

small numbers. The land is used primarily for residential and industrial purposes.

3.3.4.2 The Stauffer Chemical-Florida Process

Phosphate ore mined in Florida is shipped to the plant by rail continously throughout the year. Only a small ore stockpile is maintained on site. When functioning, the plant operates 24 hours per day, 365 days per year. A schematic of plant operations is provided in Figure 3-15.

The ore cars are emptied into a pit from which hooded conveyer belts transfer the ore to a feed bin. The kiln feed hoppers include a fines recycle feed hopper (coke dust, nodule and ore transfer dust) and provide blended feed ore and recycle dust to the rotary kiln by a hooded belt conveyer feeder. The rotary kiln produces large, stable agglomerates (nodules), which are required for proper operation of the electric reduction furnace. The rotary kiln heats the ore to its incipient melting point (about 1300°C), and the tumbling action causes the ore to agglomerate into the desired nodular form. The rotary kiln is fueled with carbon monoxide generated in the electric reduction furnace operation. The kiln offgas is vented into an offgas treatment operation consisting of eight Buell cyclones and a spray scrubbing tower. The wet scrubber uses a lime scrubbing liquor to remove fluorine, P_2O_5, and particulates. The hot nodules are passed through a processing sequence of nodule cooling, crushing, and screening. The appropriately sized nodular material is sent to nodule storage, and the fines are sent to the nodule fines roaster. The offgas stream from the nodule cooler is treated sequentially by a saturation pre-scrub cooler, a Turbulaire wet scrubber, and a cyclone separator. The nodule crushing/screening system offgas is treated with a Rotoclone.

The nodule fines roaster is a rotary kiln that also receives the sludge resulting from the phosphorus filtering operation. The nodule fines and sludge roasting operation is used to recover residual phosphorus. The roaster offgases are treated with a spray tower condenser.

Following the sizing operation, the nodular material is sent to the proportioning building where it is stored in one of three nodule storage silos. Metallurgical grade coke is sized on site and stored in the coke storage silo in the proportioning building. Silica is brought to the plant by rail and is stored in the silica storage silo. The nodules, coke, and

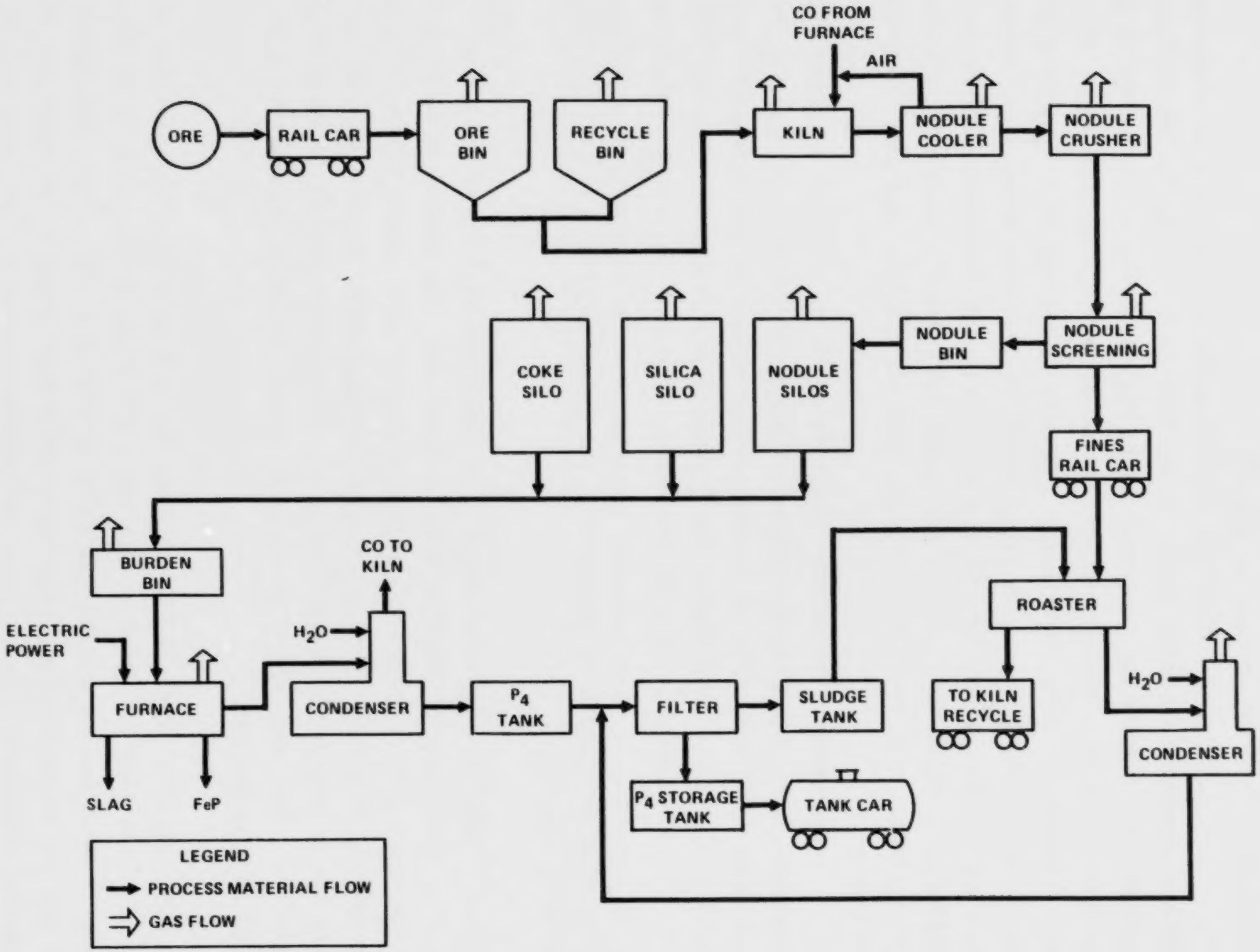

CO FROM FURNACE
AIR
ORE
RAIL CAR
ORE BIN
RECYCLE BIN
KILN
NODULE COOLER
NODULE CRUSHER
COKE SILO
SILICA SILO
NODULE SILOS
NODULE BIN
NODULE SCREENING
FINES RAIL CAR
BURDEN BIN
CO TO KILN
ELECTRIC POWER
H_2O
FURNACE
CONDENSER
P_4 TANK
FILTER
SLUDGE TANK
ROASTER
TO KILN RECYCLE
H_2O
CONDENSER
SLAG
FeP
P_4 STORAGE TANK
TANK CAR
LEGEND
PROCESS MATERIAL FLOW
GAS FLOW

Figure 3-15. Simplified Process Flow Diagram for the Stauffer Chemical-Florida Plant.

silica are mixed using a proportioning weighing system. This furnace burden is moved by a hooded belt conveyer that loads the material into the elevated burden bins. The enclosed burden bins are located above the furnace and continuously feed the furnace by gravity.

At this plant, Stauffer Chemical operates one electric reduction furnace. Operating temperatures range from 1400 to 1800°C. The furnace operates continuously and is periodically tapped to remove the molten slag and ferrophosphorus that accumulate at the bottom. Slag taps occur about every 3 hours for 30 to 90 minutes. The slag is allowed to flow into a dry pit for solidification. It is then cooled and fractured using spray water. The slag is then loaded into trucks by a front-end loader and hauled to a contractor's plant for crushing and classification and eventual sale for road ballast. The ferrophosphorus is chilled, crushed, and sold to metal processors.

The furnace offgases, composed of mainly carbon monoxide and phosphorus, are drawn through a condenser where the gases are cooled and the phosphorus condenses. The CO is then either routed to the rotary kiln and burned or flared to atmosphere. The condensed phosphorus is collected in a tank, filtered and displaced to underwater storage. The stored phosphorus is top loaded into water-sealed railroad cars for shipment to Stauffer Chemical plants where it is combined with other elements to make various phosphate compounds.

3.3.4.3 Stauffer Chemical-Florida Plant Feed Materials Characterization

The Stauffer Chemical-Florida plant uses the same feed materials as the basic process plant described in Section 3.2. Table 3-21 provides the sources and typical values for the composition, quantities used per short ton of phosphorus produced, and the radionuclide content of these feed materials. The range of values for the typical quantity reported is estimated as ± 10 percent.

3.3.4.4 Stauffer Chemical-Florida Plant Product Materials Characterization

The Stauffer Chemical-Florida plant produces the same basic products as described in Section 3.2. Table 3-22 provides the sales destination and typical values for the composition, quantities produced per short ton of elemental phosphorus produced, and the radionuclide content of these product

Table 3-21. Stauffer Chemical-Florida Phosphorus Plant Feed Materials Characterization.

Characteristic	Phosphate Ore	Coke	Silica
1. Source	Florida ore via Agrico Chemical Company	Southeastern suppliers	Mined in local coal beds
2. Chemical composition, wt %(1)			
P_2O_5	28.7	-	-
SiO_2	8.3	3.3(2)	97
CaO	43.8	-	0.3(2)
Al_2O_3	1.5	1.3(2)	1.5(2)
Fe_2O_3	2.0	0.3(2)	1.0(2)
C	-	>85	-

Table 3-21. Stauffer Chemical-Florida Phosphorus Plant Feed Materials Characterization. (Continued)

Characteristic	Phosphate Ore	Coke	Silica
3. Radionuclide content, pCi/g(3)			
U-238	55(4)	0.1	1.1
Th-230	44(4)	0.2	0.2
Ra-226	53(4)	0.5	0.2
Pb-210	60(4)	0.06	0.08
Po-210	59(4)	0.03	0.03
4. Feed material utilization, ton/ton P_4 produced(2)	9.4	1.2	1.45
5. Electrical power, kWh/short ton P_4 produced(3)	13,000		

(1) Typical values for Florida phosphate ores. Assumed same as Mobil Chemical plant.

(2) SAI engineering estimates based on data from other plants.

(3) Data presented to SAI staff at November 9, 1982, meeting at Stauffer Chemical Elemental Phosphorus Plant at Mt. Pleasant, TN.

(4) Data from Ref. [22].

Table 3-22. Stauffer Chemical-Florida Phosphorus Plant Product Materials Characterization.

Characteristic	Phosphorus	Slag	Ferrophosphorus
1. Sales destination(1)	Stauffer Chemical	Sold locally	Sold to steel industry
2. Utilization(1)	Chemical production	Railroad ballast & road beds	
3. Chemical composition,wt%(2)			
SiO_2	-	43	-
CaO	-	47	-
Al_2O_3	-	5.5	-
Fe_2O_3	-	0.5	-
P_2O_5	-	1.7	-
P	>99.9	-	23
Fe	-	-	70
V	-	-	3.0
Cr	-	-	0.25

Table 3-22. Stauffer Chemical-Florida Phosphorus Plant Product Materials Characterization. (Continued)

Characteristic	Phosphorus	Slag	Ferrophosphorus
4. Radionuclide content, pCi/g(1)			
U-238	-	54	88
Th-230	-	54	88
Ra-226	-	67	18
Pb-210	-	6.3	12
Po-210	-	0.8	0.7
5. Production, ton/ton P_4 produced(3)	1.0	7.9	0.09

(1) Data presented to SAI staff at November 9, 1982, meeting at Stauffer Chemical Elemental Phosphorus Plant in Mt. Pleasant, TN.

(2) Assumed similar to other plants in the southeast.

(3) SAI engineering estimates.

materials. The range of values for the typical quantity reported is estimated as ± 10 percent.

3.3.4.5 Stauffer Chemical-Florida Plant Waste Materials

The Stauffer Chemical-Florida plant has a minor quantity of waste materials. Only the phossy water and sludge remain on site in appreciable quantities. The phossy water is recycled, and the plant scrubber sludge residues are stored in clay-lined ponds, which are dredged and recycled.

Used furnace brick is recycled, and scrap metal is decontaminated as necessary and sold for scrap at salvage value.

3.3.4.6 Stauffer Chemical-Florida Process Airborne Emissions and Sources Characterization

A key objective of this study was to identify and characterize the major airborne emission points. To fulfill this objective, plant operating permits at the Florida State Department of Environmental Regulation in Tampa, Florida, were obtained and a literature review was conducted. The plant was not toured, but Stauffer Chemical staff members were interviewed November 9, 1982, at the Stauffer Chemical plant in Tennessee.

Emission points were divided into point sources, vents, and fugitive sources. This section only reports emission sources and characterizes the emissions. The related air pollution control equipment is described in Chapter 4.

Point Sources

Table 3-23 lists the air pollution sources, emission points, and control equipment (characterized in Chapter 4). Point source emissions are generally continuous.

Vents

Table 3-24 lists the vents, including emergency vents, air pollution sources, emission points, and control equipment (characterized in Chapter 4). Vent emissions are intermittent.

Table 3-23. Point Sources of Airborne Emissions for the Stauffer Chemical-Florida Plant.

Air Pollution Source	Emission Points	Control Equipment
Enclosed ore handling system	Hooded transfer from railcar track hopper to storage bins	Baghouse filter
	Hooded transfer from storage bins to kiln feeder lift elevator	Baghouse filter
Rotary kiln	Kiln scrubber stack	Buell cyclones, spray tower scrubber
Nodule cooler and sizing system	Nodule cooler and sizing system stack	Saturation pre-scrub cooler, Turbulaire scrubber, cyclone separator
Nodule transfer points	Nodule transfer system stack	Rotoclone
Coke sizing and handling	Coke system stack	Rotoclone
Feed proportioning system	Silo materials feed system stack	Baghouse filter
	Materials weighing/ handling system stack	Baghouse filter
	Proportioning to burden bin materials handling system stack	Rotoclone
Electric furnace offgas condenser	Condenser spray tower stack	Lane condenser
Furnace taphole fume scrubber	Taphole fume stack	Venturi scrubber, cyclone separator
Phosphorus handling area	Phosphorus handling area stack	Clermont scrubber
Roaster offgas condenser	Roaster offgas condenser stack	Water spray condenser

Table 3-24. Vents and Emergency Vents for the Stauffer Chemical-Florida Plant.

Air Pollution Source	Emission Points	Control Equipment
Furnace ESP explosion relief vents (ERV)	Furnace ERV	-
Furnace pressure relief system (PRV)	Furnace PRV	-
Kiln CO flare	Kiln CO flare	-

Fugitive Sources

The fugitive emission sources are the slag pit, handling and stockpile areas; plant roads; and miscellaneous furnace leaks. Each of these areas is discussed below.

- Slag Pit, Handling and Stockpiles

  The slag pit and handling and stockpile area are defined as fugitive emission sources. The molten slag tapped from the furnaces flows by gravity into a dry pit located adjacent to the furnace building. The slag is cooled, fractured, recovered by front-end loaders and hauled by truck to a contractor's plant. The cooling, digging, hauling, and storage causes clouds of water vapor, dust, and P_2O_5 fumes.

- Miscellaneous Furnace Leaks

  Each furnace has three carbon electrodes that are continuosly fed into the furnace. To prevent furnace gas from leaking around the electrodes, they are equipped with Stauffer Chemical-designed seals. However, periodic pressure surges caused by bridging and collapse of material in the furnace allow gases to leak into the building.

- Plant Roads

  The plant roads are paved and travel on these roads causes only minor fugitive dust emissions.

Key Sources of Radionuclide Emissions

The estimated annual particulate radionuclide emissions from the Stauffer Chemical-Florida plant are summarized in Table 3-25. These emissions are dominated by volatilized Pb-210 and Po-210 releases from the kiln operation of approximately 7200 pCi/s (0.23 Ci/yr) and 5400 pCi/s (0.17 Ci/yr), respectively. In addition, about 50 pCi/s (0.0016 Ci/yr) of each of these radionuclides are emitted from the furnace taphole fume scrubbing system. Relatively minor quantities of particulate U-238, Th-230, and Ra-226 are emitted (about 0.004-0.005 Ci/yr), with the main sources of these

Table 3-25. Stack and Emission Data for the Stauffer Chemical-Florida Elemental Phosphorus Plant.

Source	Stack Geometry		Stack Gas Characteristics				Particulate Emissions		Radionuclide Emissions pCi/s (Ci/yr)				
	Height (m)	Diameter (m)	Flow (ACMM)	Exit Velocity (m/s)	Exit Temperature C° (K°)	Heat Release (cal/s)	(g/m^3)	(g/s)	U-238	Th-230	Ra-226	Pb-210	Po-210
Ore belt transfer	19.5	0.3	140	32.0	21 (294)	0	0	0	0	0	0	0	0
Ore belt unloading(1)	21.6	0.3	140	32.0	21 (294)	0	0.03	0.06	3.3	2.6	3.2	3.6	3.5
Kiln(1)	48.8	1.2	924	13.8	64 (357)	1.7×10^5	0.15	2.34	130	100	120	7200	5400
Oscill. grate undercooler(2)	24.4	1.8	1954	12.9	52 (325)	2.7×10^5	0.01	0.33	15	14	17	18	18
Crusher/screen(2)(3)	9.1	0.7	504	22.0	52 (325)	6.9×10^4	-	0.08	3.6	3.3	4.1	4.5	4.5
Roaster/condenser			No Stack Data				Not Estimable						
Coke sizing and handling(4)			No Stack Data					0.6	0.06	0.12	0.3	0.04	0.02
Burden bin(2)	-	-	236	-	-	-	-	0.25	11	10	13	14	14
Furnace tapholes(5)	-	-	626	-	-	-	-	0.9	-	-	-	50	50
Furnace condenser mist eliminator tower	18.6	0.3	-	-	-	-	Not Estimable						
Totals								4.56	160 (0.0051)	130 (0.0041)	160 (0.005)	7300 (0.23)	5500 (0.17)

(1) Assumes radionuclide concentrations in particulate emissions same as that in PO_4 ore for U-238, Th-230, and Ra-226; for Pb-210 and Po-210 emissions, estimates are based on Stauffer Chemical-MT kiln emissions factored by differences in radionuclide concentrations in ore and ore process rates.

(2) Assumes radionuclide concentrations in particulate emissions same as that in nodules.

(3) Estimated from data of oscillating grate undercooler stack (factored by differences in flow rate).

(4) Assumes radionuclide concentration in particulate emissions same as that in coke.

(5) Assumes emissions have Pb-210 and Po-210 concentrations of 55 pCi/g [22].

radionuclides being the kiln offgas, nodule cooler, and burden bin scrubber stacks.

The rate of Rn-222 emission during the phosphorus production process is estimated at 10 Ci/yr using radon release data from the Stauffer Chemical-Montana plant in conjunction with differences in quantities of Ra-226 processing capacity.

The surface area of the Stauffer Chemical-Florida ore stockpile is currently only about 2900 m^2. Using an estimated Rn-222 emanation rate of 236 pCi/m^2-min [22] results in an annual Rn-222 release of about 0.36 Ci. There is currently no significant slag stockpile at the Stauffer Chemical-Florida plant.

Activity Balance

The flow of radioactivity through the Stauffer Chemical-Florida plant process is illustrated in Figure 3-16. These data seem to indicate that virtually all of the input U-238, Th-230, and Ra-226 can be accounted for in the output slag. Discrepancies in input and output Ci/yr totals for specific radionuclides are attributed to uncertainty in analytical data used. Of the input Pb-210 and Po-210, about 80-90 percent is not accounted for in plant products or air emissions. This material is presumably transported by scrubber effluents to the liquid settling ponds.

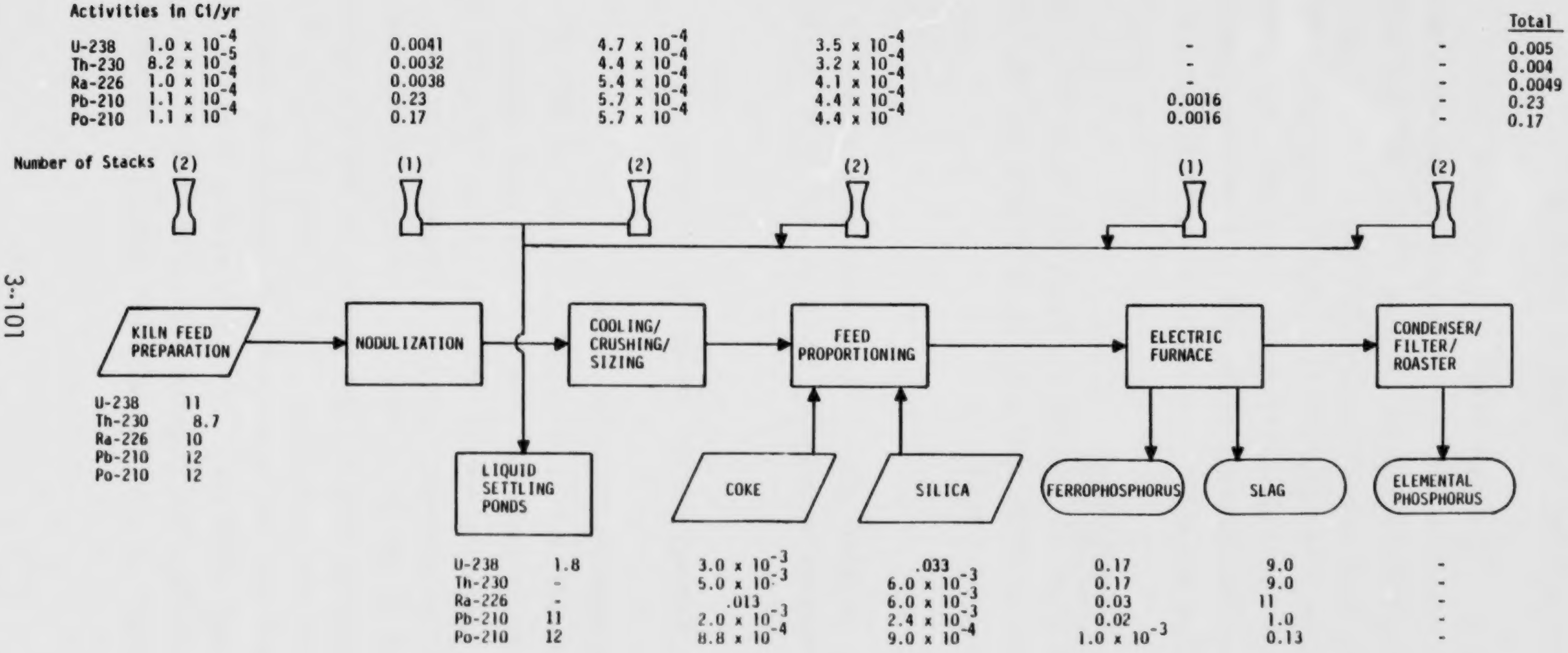

Activities in Ci/yr
U-238 1.0×10^{-4}
Th-230 8.2×10^{-5}
Ra-226 1.0×10^{-4}
Pb-210 1.1×10^{-4}
Po-210 1.1×10^{-4}
0.0041
0.0032
0.0038
0.23
0.17
4.7×10^{-4}
4.4×10^{-4}
5.4×10^{-4}
5.7×10^{-4}
5.7×10^{-4}
3.5×10^{-4}
3.2×10^{-4}
4.1×10^{-4}
4.4×10^{-4}
4.4×10^{-4}
-
-
-
0.0016
0.0016
-
-
-
-
-
Total
0.005
0.004
0.0049
0.23
0.17
Number of Stacks (2)
(1)
(2)
(2)
(1)
(2)
KILN FEED PREPARATION
NODULIZATION
COOLING/ CRUSHING/ SIZING
FEED PROPORTIONING
ELECTRIC FURNACE
CONDENSER/ FILTER/ ROASTER
U-238 11
Th-230 8.7
Ra-226 10
Pb-210 12
Po-210 12
LIQUID SETTLING PONDS
COKE
SILICA
FERROPHOSPHORUS
SLAG
ELEMENTAL PHOSPHORUS
U-238 1.8
Th-230 -
Ra-226 -
Pb-210 11
Po-210 12
3.0×10^{-3}
5.0×10^{-3}
.013
2.0×10^{-3}
8.8×10^{-4}
.033
6.0×10^{-3}
6.0×10^{-3}
2.4×10^{-3}
9.0×10^{-4}
0.17
0.17
0.03
0.02
1.0×10^{-3}
9.0
9.0
11
1.0
0.13
-
-
-
-
-

Figure 3-16. Activity Balance for the Stauffer Chemical-Florida Plant.

3.3.5 Monsanto Plant - Columbia, Tennessee

3.3.5.1 Monsanto-Tennessee Plant Site Characterization

The Monsanto-Tennessee elemental phosphorus plant is located 8 km northwest of Columbia, Tennessee, at 35° 40' 00" latitude and 87° 07' 02" longitude and at an elevation of about 182 m. The plant lies on the Duck River downstream from Columbia in a high-density strip mining region and a hilly area with numerous small creeks and ponds. The plant is accessed by road from the Jim McCord Highway and by a railroad spur. A map indicating the general area and major features is shown in Figure 3-17.

Meteorology and Air Quality

The plant is located in Maury County and has the same meteorological and air quality conditions as described for the Stauffer-Tennessee plant (see Section 3.3.3.1).

Demography

See Section 3.3.3.1 for county population statistics. Actual population densities surrounding the plant are given in Appendix A.

Land Use

See Section 3.3.3.1 for county land use.

3.3.5.2 The Monsanto-Tennessee Process

Phosphate ore is shipped to Monsanto by rail from local Tennessee strip mining operations. At times, a very small quantity of Florida phosphate ore is also received by rail. (Currently, only Tennessee ore is being used.) Ore is shipped continuously throughout the year and only a small stockpile (one to two weeks supply) is accumulated at any time. The plant has two ore washing systems that receive raw ore and separate this material from phosphate sand and rock. The process consists of a spray washing system that can and does operate for 30 minutes or longer independently of the other plant processes. This processing step has surge capacity at either end and does not require pollution control equipment. The plant operates 24 hours per day, 365 days per year. It functions as a swing plant,

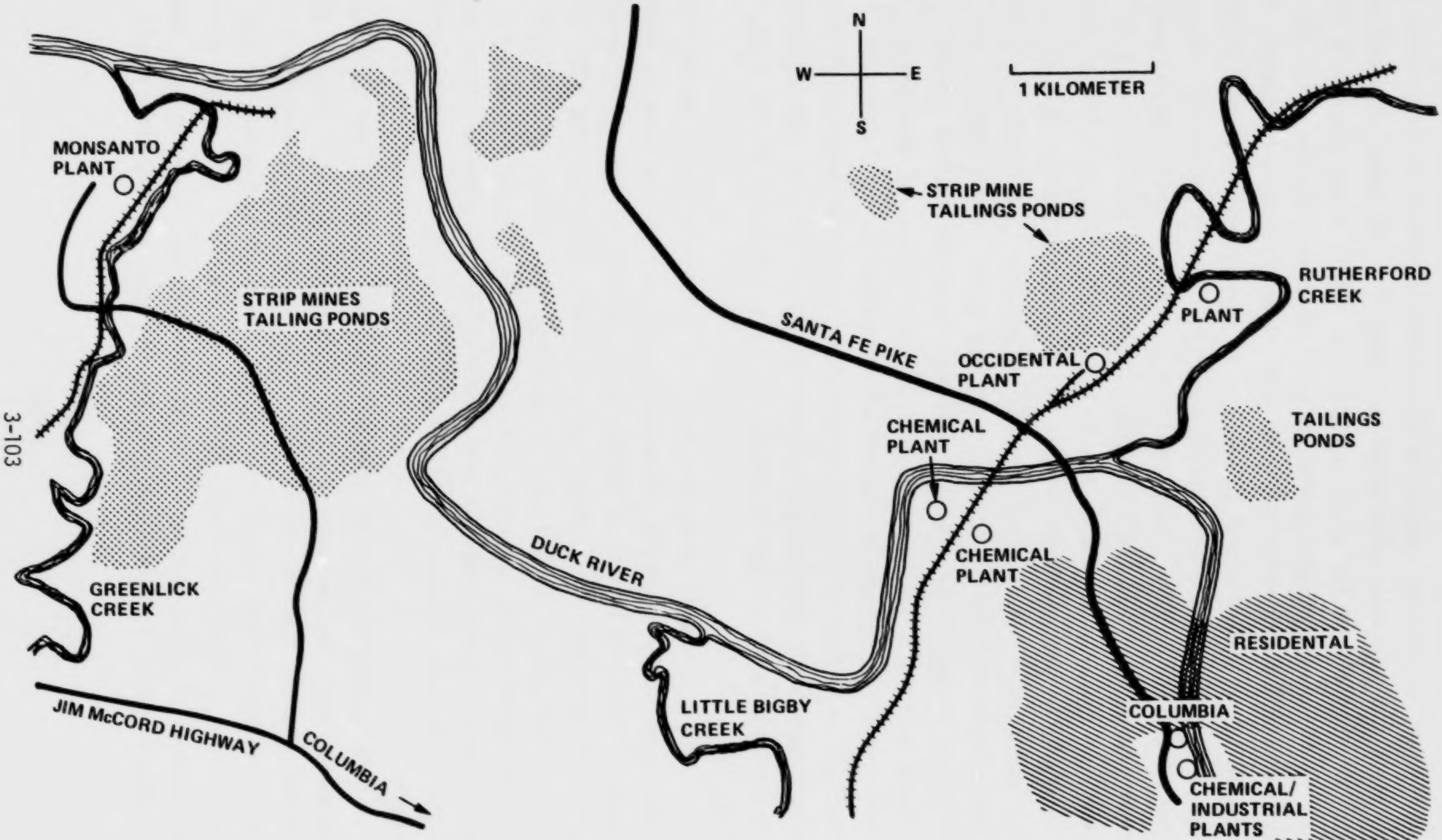

N
W
E
S
1 KILOMETER
MONSANTO PLANT
STRIP MINES TAILING PONDS
STRIP MINE TAILINGS PONDS
RUTHERFORD CREEK
PLANT
SANTA FE PIKE
OCCIDENTAL PLANT
TAILINGS PONDS
CHEMICAL PLANT
CHEMICAL PLANT
DUCK RIVER
GREENLICK CREEK
RESIDENTAL
COLUMBIA
LITTLE BIGBY CREEK
JIM McCORD HIGHWAY
COLUMBIA
CHEMICAL/ INDUSTRIAL PLANTS

Figure 3-17. Monsanto-Tennessee Plant Site Area.

producing the incremental amount of phosphorus necessary to supplement that produced in the Monsanto-Idaho plant for supplying Monsanto chemical plant needs. A schematic of the plant operation is provided as Figure 3-18 [23].

The washed phosphate ore and dust recycled from the kilns and the screening plant are stockpiled in an open, raw materials craneway. From there, the materials are sent to one of two stockpiles. As one stockpile accumulates, the other stockpile is used for feeding the kilns. The ores are initially blended by the stockpiling process in the craneway and are further blended by reclaiming perpendicularly to the long axis of the stockpile. The blended ore is fed to the rotary kilns by belt conveyers. The rotary kilns produce large, stable agglomerates (nodules) that allow for proper operation of the electric reduction furnaces. The rotary kilns raise the ore temperature to its incipient melting point (about 1300°C), and the tumbling action causes the ore to agglomerate into the desired nodular form. The rotary kilns are fueled with coal and carbon monoxide generated in the electric reduction furnace operation and supplemental coal as needed. The kiln offgas is vented into kiln-specific and identical sequential offgas treatment operations consisting of cyclones, spray towers, and demisters. The wet scrubbers use a lime scrubbing liquor to remove fluorine, P_2O_5, and particulates.

The hot nodules from each kiln are passed through a nodule cooler and are conveyed by a series of hooded conveyers to the nodule storage craneway or directly to one of three nodule sizing systems. A clamshell bucket on an overhead crane moves the nodules to storage bins from which they pass through the nodule sizing systems. The nodule sizing systems consist of crushing and screening operations with a number of options for materials flow. Fines from the sizing operations are recycled to be mixed with the kiln feed. Each nodule sizing system has a Rotoclone for offgas treatment.

Following sizing, the nodular material is stored and transferred by hooded conveyer to the proportioning building as needed. Coke is dried and sized on site, and the sized coke is stored in bins feeding the burden scales. Washed silica is also stored in a bin feeding the burden scales. At the burden scales, the coke, silica, and nodules are mixed using a proportioning weighing system. This mixture (burden) is moved by a hooded belt conveyer to an intermediate transfer bin that distributes it into one

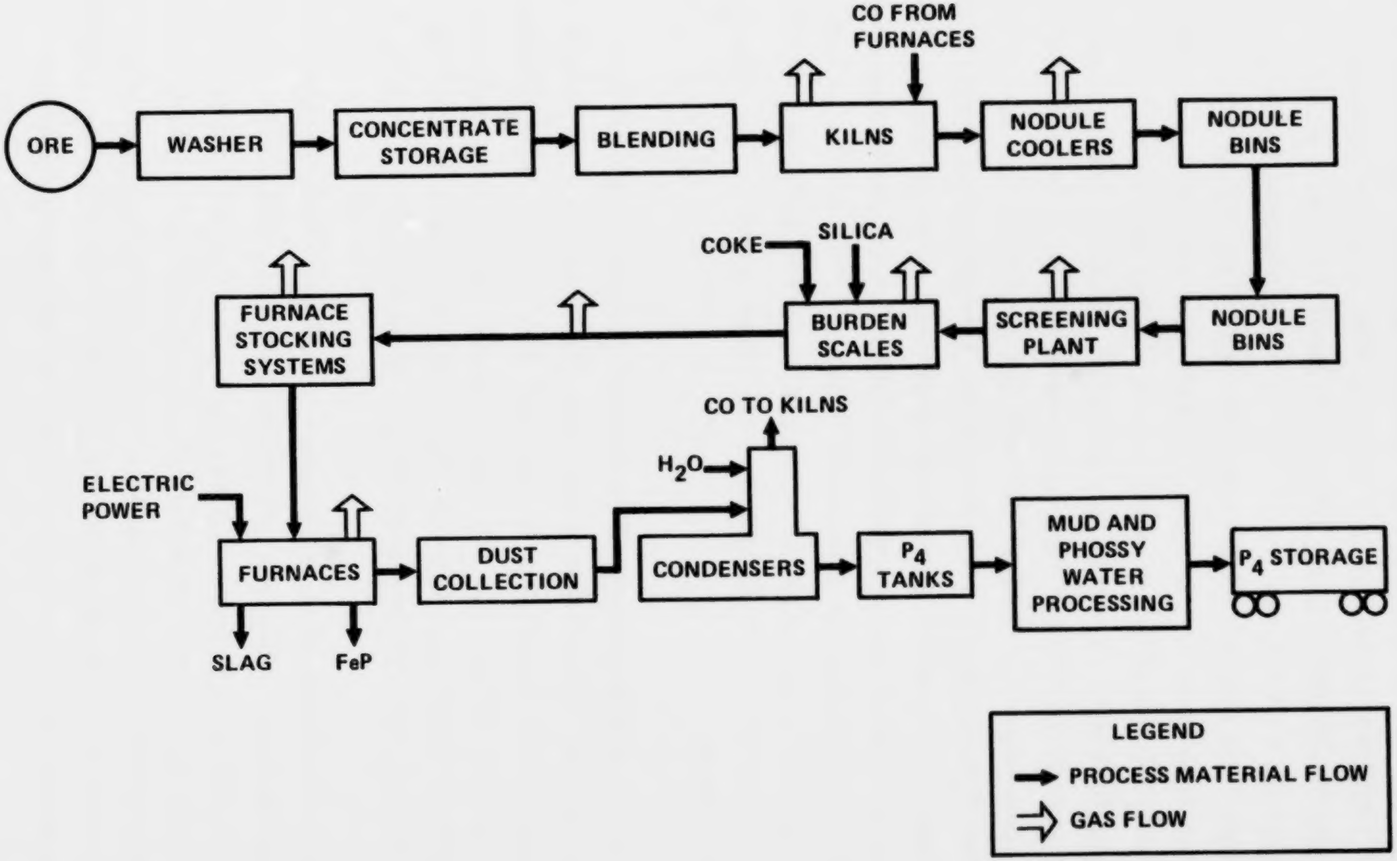

ORE
WASHER
CONCENTRATE STORAGE
BLENDING
KILNS
CO FROM FURNACES
NODULE COOLERS
NODULE BINS
NODULE BINS
SCREENING PLANT
BURDEN SCALES
COKE
SILICA
FURNACE STOCKING SYSTEMS
ELECTRIC POWER
FURNACES
SLAG
FeP
DUST COLLECTION
CO TO KILNS
H_2O
CONDENSERS
P_4 TANKS
MUD AND PHOSSY WATER PROCESSING
P_4 STORAGE
LEGEND
PROCESS MATERIAL FLOW
GAS FLOW

Figure 3-18. Simplified Process Flow Diagram for the Monsanto-Tennessee Plant [23].

of six furnace feed hoppers. The feed hoppers are located above the furnaces and continuously feed the furnaces by gravity.

At its Tennessee plant, Monsanto operates six electric furnaces that operate at 1400 to 1800°C. The furnaces operate continuously and are periodically tapped to remove the molten slag and ferrophosphorus that accumulate at the bottom. Slag taps occur about 12 times each 8-hour shift and last about 20 minutes per tap. The ferrophosphorus is tapped once or twice per day. The molten slag is tapped into slag ladles that are transported to and poured onto the slag storage pile at the site. The ferrophosphorus slag is collected in chill molds, cooled and sold.

The furnace offgases, composed of mainly carbon monoxide and phosphorus, are drawn through dust collecters (on four furnaces) or through Monsanto proprietary dust removal systems (on two furnaces) for particulate removal. The cleaned gases are then routed through water spray condensers where the gases cool and the phosphorus condenses. The condensed phosphorus is collected in tanks, sent to settling tanks for sludge and phossy water removal, and then pumped to underwater storage. The stored phosphorus is bottom loaded into water-sealed railroad cars for shipment to Monsanto chemical plants where it is combined with other elements to make various phosphate compounds.

3.3.5.3 Monsanto-Tennessee Plant Feed Materials Characterization

The Monsanto-Tennessee plant uses the same feed materials as the basic process plant described in Section 3.2. Table 3-26 provides the sources and typical values for the composition, quantities used per short ton of phosphorus produced, and the radionuclide content of the feed materials. The values are typical with ranges estimated at ± 10 percent.

3.3.5.4 Monsanto-Tennessee Plant Product Materials Characterization

The Monsanto-Tennessee plant produces the same basic products as described in Section 3.2. Monsanto has made a corporate decision to store the slag product as a waste material until an industry standard or regulation providing guidelines for commercial utilization is promulgated. Table 3-27 provides the sales destination and typical values for the composition, quantities produced per short ton of elemental phosphorus produced, and the

Table 3-26. Monsanto-Tennessee Phosphorus Plant Feed Materials Characterization.

Characteristic	Phosphate Ore	Coke	Silica
1. Source	Local Tennessee strip mines	Decatur, Alabama	Tennessee River
2. Chemical Composition, wt %(1)			
P_2O_5	26.5	-	-
SiO_2	16	3.3	96
CaO	36.5	-	0.25
Al_2O_3	3.5	1.3	1.5
Fe_2O_3	5.5	0.3	1.0
C	-	90	-
3. Radionuclide content, pCi/g(2)			
U-238	2.7	0.4	0.3
Th-230	3.6	0.6	1.1
Ra-226	3.1	0.5	0.4
Pb-210	4.2	0.9	1.0
Po-210	4.1	0.8	0.8

Table 3-26. Monsanto-Tennessee Phosphorus Plant Feed Materials Characterization. (Continued)

Characteristic	Phosphate Ore	Coke	Silica
4. Feed material utilization, ton/ton P_4 produced(3)	19.0	1.7	0.2
5. Electrical power, kWh/short ton P_4 produced(4)	13,200		

(1) Assumed identical to materials used at Occidental Chemical Plant.

(2) Data from Ref. [23]

(3) SAI engineering estimates.

(4) Data presented to SAI staff at November 3, 1982, meeting at Monsanto's Elemental Phosphorus Plant in Soda Springs, Idaho.

Table 3-27. Monsanto-Tennessee Phosphorus Plant Product Materials Characterization.

Characteristic	Phosphorus	Slag	Ferrophosphorus
1. Sales destination(1)	Monsanto chemical plants	Stored on site	Tennessee company
2. Utilization(1)	Chemicals production	-	Sold locally
3. Chemical Composition,(2) wt %			
SiO_2	-	44	-
CaO	-	47	-
Al_2O_3	-	5.5	-
Fe_2O_3	-	-	-
P_2O_5	-	1.5	-
P	>99.9	-	23
Fe	-	-	70
V	-	-	3.0
Cr	-	-	0.25

Table 3-27. Monsanto-Tennessee Phosphorus Plant Product Materials Characterization. (Continued)

Characteristic	Phosphorus	Slag	Ferrophosphorus
4. Radionuclide content, pCi/g(3)			
U-238	-	11	9.7
Th-230	-	22	0.05
Ra-226	-	12	0.2
Pb-210	-	1.5	3.9
Po-210	-	<0.8	1.0
5. Production, ton/ton P_4 produced(4)	1.0	7.5	0.34

(1) Data presented to SAI staff at November 3, 1982, meeting at Monsanto's Elemental Phosphorus Plant in Soda Springs, Idaho.

(2) Assumed identical to materials at Occidental Plant.

(3) Data from Ref. [23].

(4) SAI engineering estimates.

radionuclide content for these products. The range of values for the typical quantity reported is estimated at ±10 percent.

3.3.5.5 Monsanto-Tennessee Plant Waste Materials

The Monsanto-Tennessee plant generates only minor quantities of waste materials. All slurry solids, dust collection solids, and phossy water are recycled. Slag is stockpiled on site for either future sale or disposal.

Used furnace brick, scrap metal, and other plant wastes are cleaned and sold for scrap at salvage values except for a very small quantity of construction rubble, which is disposed of on site.

3.3.5.6 Monsanto-Tennessee Process Airborne Emissions and Sources Characterization

A key objective of this study was to identify and characterize the major airborne emission points. To fulfill this objective, plant operating permits at the Tennessee Department of Public Health, Air Pollution Control Division, in Nashville, Tennessee, were obtained and a literature review was conducted. This plant was not toured but key Monsanto staff members were interviewed at the Monsanto-Idaho plant on November 3, 1982.

Emission points were divided into point sources, vents, and fugitive sources. This section only reports emission sources and characterizes the emissions. The related air pollution control equipment is described in Chapter 4.

Point Sources

Table 3-28 lists the air pollution sources, emission points, and control equipment (characterized in Chapter 4). Point source emissions are generally continuous.

Vents

Table 3-29 lists the vents, including emergency vents, air pollution sources, emission points, and control equipment (characterized in Chapter 4). Vent emissions are intermittent.

Table 3-28. Point Sources of Airborne Emissions for the Monsanto-Tennessee Plant.

Air Pollution Source	Emission Points	Control Equipment
#1 rotary kiln & #1 nodule cooler	#1 kiln scrubber stack #1 kiln cooler stack	Cyclone, spray tower scrubber, jet eductor scrubber
#2 rotary kiln & #2 nodule cooler	#2 kiln scrubber stack #2 kiln cooler stack	Cyclone, spray tower scrubber, jet eductor scrubber
#3 rotary kiln & #3 nodule cooler	#3 kiln scrubber stack #3 kiln cooler stack	Cyclone, spray tower scrubber, jet eductor scrubber
#1 nodule sizing system	#1 sizing system stack	Rotoclone
#2 nodule sizing system	#2 sizing system stack	Rotoclone
#3 nodule sizing system	#3 sizing system stack	Rotoclone
Coke dryer	Coke dryer stack	Cyclone, venturi scrubber
Coke sizing system	Coke screen stack	Baghouse
	Coke silo stack	Baghouse
	Coke unloading area stack	Baghouse
Feed proportioning system	South burden scales stack	Baghouse
	North burden scales stack	Baghouse
Feed transfer system	North burden feed transfer stack	Baghouse
	South burden feed transfer stack	Baghouse
	Central burden feed transfer stack	Baghouse
Furnace feed systems	North furnaces feed stack	Baghouse
	South furnace feed stack	Baghouse

Table 3-28. Point Sources of Airborne Emissions for the Monsanto-Tennessee Plant. (Continued)

Air Pollution Source	Emission Points	Control Equipment
#1 through #6 furnace tapping systems, each	Furnace taphole fume stacks	Venturi scrubber, cyclonic separator
#1 through #6 furnace offgas systems, each	CO flare stacks	Individual water spray tower condenser system treating each furnace offgas

Table 3-29. Vents and Emergency Vents for the Monsanto-Tennessee Plant.

Air Pollution Source	Emission Points	Control Equipment
Kiln CO flare	Kiln CO flare stack	-
Low pressure CO main	#1 emergency vent flare stack	-
	#2 emergency vent flare stack	-
#1 through #6 furnace CO flares, each	#1 through #6 furnace CO flare stacks	Wet scrubber
#1 through #6 furnace pressure seals, each	#1 through #6 engineering ventover stacks	-

Fugitive Emission Sources

The fugitive emission sources are the slag pit, handling and stockpile areas; plant roads; miscellaneous furnace leaks; and phosphate ore stockpile. Each of these areas is discussed below.

- Slag Pit, Handling and Stockpile

  The slag pit and handling and stockpile areas are defined as fugitive emission sources. The molten slag tapped from the furnaces flows by gravity into a ladle and is transferred in its molten state by front-end loaders that haul it to the slag storage pile. The dumping of the molten slag raises very small amounts of water vapor, dust, and P_2O_5 fumes during wet weather. After cooling, the pile becomes nearly monolithic in structure and is not a source of fugitive dust.

- Miscellaneous Furnace Leaks

  Each furnace has three carbon electrodes continuously fed into the furnace. To prevent furnace gas from leaking around the electrodes, they are equipped with Monsanto-designed seals. However, periodic pressure surges caused by bridging and collapse of material in the furnace allows very small quantities of gases to leak into the building.

- Plant Roads

  Some plant roads are paved. Water spraying of unpaved roads during dry periods to control fugitive emissions is standard practice.

- Ore Stockpile

  The ore stockpiles are not generally a significant source of fugitive dust because of the moisture content of the ore. However, during dry conditions, dust can be generated from the stockpiles.

Key Sources of Radionuclide Emissions

The estimated annual particulate radionuclide emission rates for the various sources within the Monsanto-Tennessee plant are presented in Table 3-30. These results show that the kilns used for nodulization are the principal sources of emissions and that these emissions consist primarily of Pb-210 and Po-210. The temperatures and ore residence times in the nodulization process volatilize much of the lead and polonium present in the feed material. Even though significant amounts of Pb-210 and Po-210 are released to the atmosphere from this source, most is removed from the effluent stream by the kiln spray towers. The spray towers use limed water as a scrubbing medium. Samples of spray tower discharge show relatively high concentrations of volatile radionuclides (about 990 pCi/l for Pb-210 and 1700 pCi/l for Po-210). This discharge is channeled to a pond, which allows the suspended particulate material to settle.

Other nontrivial sources of emissions are the nodule screening plant and the furnace taphole fume scrubber stacks. The screening plant stacks emit significant quantities of particulate material, presumably with the same radionuclide concentrations as nodules. The furnace taphole fume scrubber stacks release about 470 pCi/s (0.015 Ci/yr) of Pb-210, and 26 pCi/s (8.2×10^{-4} Ci/yr) of Po-210. Most of this release occurs during ferrophosphorus taps [23].

An EPA-sponsored survey of this plant indicated that approximately 9.6 Ci of Rn-222 are also discharged annually, with the kilns being the source of virtually all this release [23]. The EPA survey, however, occurred when the plant was using a blend of Tennessee and Florida ores; only Tennessee ores are currently being used. Radionuclide concentrations in the blended kiln feed are reportedly about 82 percent higher than Tennessee ore for U-238, 61 percent higher for Th-230, 68 percent higher for Ra-226, 51 percent higher for Po-210, and essentially equal for Pb-210 [23]. Thus, to assess the emissions resulting from the use of Tennessee ore alone, the emission estimates should be corrected by these factors.

The level of uncertainty for current emission rates is very difficult to estimate. For the nodule kiln stacks, by far the most important sources of emissions, these emission rates are estimated to be accurate to within a factor of about two.

Table 3-30. Stack and Emission Data for the Monsanto-Tennessee Elemental Phosphorus Plant(1).

Source	Stack Geometry		Stack Gas Characteristics				Particulate Emissions		Radionuclide Emissions pCi/s (Ci/yr)				
	Height (m)	Diameter (m)	Flow (ACMM)	Exit Velocity (m/s)	Exit Temperature C° (K°)	Heat Release (cal/s)	(g/m^3)	(g/s)	U-238	Th-230	Ra-226	Pb-210	Po-210
Nodule kiln #1(2)	35.4	5.4	4397	3.2	60 (333)	9.2×10^5	0.003	0.16	22	14	21	4800	7400
Nodule kiln #2(2)	35.4	5.4	4397	3.2	60 (333)	9.2×10^5	0.003	0.16	22	14	21	4800	7400
Nodule kiln #3	35.4	5.4	4672	3.4	74 (347)	1.2×10^6	0.001	0.08	23	15	22	5100	7900
Kiln emergency flare	27.7	0.5	160	13.6	609 (882)	1.4×10^5	1.09	2.90	---- Negligible Radioactivity ----				
Nodule cooler #1(3)	17.7	4.1	1584	2.0	48 (321)	2.5×10^5	0.02	0.58	11	9	ND(4)	ND	6
Nodule cooler #2(3)	21.0	4.1	1584	2.0	48 (321)	2.5×10^5	0.02	0.44	11	9	ND	ND	6
Nodule cooler #3	25.6	4.4	1551	1.7	48 (321)	2.5×10^5	0.02	0.53	11	9	ND	ND	6
#1 screening plant(5)	28.7	1.0	975	20.7	59 (332)	2.0×10^5	0.29	4.73	35	34	36	34	16
#2 screening plant(5)	28.7	1.0	1079	22.9	62 (335)	2.3×10^5	0.03	0.52	3.9	3.7	4.0	3.7	1.7
#3 screening plant(5)	31.2	1.0	1140	24.2	46 (319)	1.8×10^5	0.15	2.90	22	21	22	21	9.6
Coke unloading area	11.0	0.6	344	20.3	30 (303)	2.6×10^4	0.002	0.01					
Coke dryer(6)	32.3	0.9	599	15.7	66 (339)	1.4×10^5	0.06	0.56	0.59	0.78	0.71	1.3	1.1
Coke silo(6)	13.4	0.3	34	8.0	37 (310)	4.6×10^3	0.01	0.004					
Chem. coke screen(6)	27.4	0.9	676	17.7	38 (311)	8.1×10^4	0.07	0.83					
South burden scales baghouse	13.4	0.9	618	16.2	59 (332)	1.3×10^5	0.06	0.61	16	16	16	ND	ND
North burden scales(7) baghouse	13.4	0.9	397	10.4	44 (317)	5.8×10^4	0.03	0.21	10	10	10	ND	ND
Stocking belt south baghouse	32.0	0.4	133	17.7	64 (337)	3.0×10^4	0.14	0.30	10	13	8.9	ND	ND
Stocking belt north baghouse	21.3	0.8	413	13.7	32 (305)	3.4×10^4	0.04	0.27					

Table 3-30. Stack and Emission Data for the Monsanto-Tennessee Elemental Phosphorus Plant. (Continued)

Source	Stack Geometry		Stack Gas Characteristics				Particulate Emissions		Radionuclide Emissions pCi/s (Ci/yr)				
	Height (m)	Diameter (m)	Flow (ACMM)	Exit Velocity (m/s)	Exit Temperature C° (K°)	Heat Release (cal/s)	(g/m^3)	(g/s)	U-238	Th-230	Ra-226	Pb-210	Po-210
North furnace stock system(8)	38.4	0.7	284	12.3	45 (318)	3.8×10^5	0.17	0.82	4.9	6.8	3.9	ND	0.7
South furnace stock system(8)	38.4	0.6	224	13.2	35 (308)	2.2×10^4	0.15	0.55	3.9	5.4	3.1	ND	0.5
Central furnace stock system	47.5	0.9	416	10.9	42 (315)	6.5×10^3	0.25	1.75	7.3	10	5.7	ND	1.0
Furnace CO flares		----------	----------	No Stack Data	----------	----------	-	-	Negligible Radioactivity				
Furnace #1, #3 CO vent	27.8	0.5	160	13.6	609 (882)	2.0×10^3	1.63	4.35					
Furnace #2, 4, 5, 6 south CO emergency vent flare	47.2	0.6	58	3.4	609 (882)	5.9×10^4	0.21	0.20					
Furnace #2, 4, 5, 6 north CO emergency vent flare	47.2	0.6	58	3.4	609 (882)	5.9×10^4	0.21	0.20					
#1 furnace taphole	38.1	1.1	787	13.8	31 (304)	6.3×10^4	0.09	1.16	ND	ND	ND	470(9)	26(9)
#2 furnace taphole	38.1	1.1	787	13.8	31 (304)	6.3×10^4	0.04	0.58					
#3 furnace taphole	38.1	1.1	787	13.8	31 (304)	6.3×10^4	0.04	0.58					
#4 furnace taphole	38.1	1.1	787	13.8	31 (304)	6.3×10^4	0.04	0.58					
#5 furnace taphole	38.1	1.1	787	13.8	31 (304)	6.3×10^4	0.09	1.16					
#6 furnace taphole	38.1	1.1	787	13.8	31 (304)	6.3×10^4	0.04	0.58					
Totals									210 (0.0067)	190 (0.006)	170 (0.0054)	15,000 (0.47)	23,000 (0.72)

(1) Radionuclide emissions data from Ref. [23] unless otherwise noted.

(2) Assumes Kiln #1 and #2 emissions are same as Kiln #3 corrected for differences in flow rates.

(3) Assumes Nodule Cooler #1 and #2 emissions are same as Nodule Cooler #3.

(4) ND = Not detected.

(5) Radionuclide emissions calculated from data on concentrations in nodules.

(6) Radionuclide emissions calculated from data on concentrations in coke.

(7) Assumes N. Burden Scales Baghouse Stack emissions are same as S. Burden Scales Baghouse Stack corrected for differences in flow rates.

(8) Assumes North and South Furnace Stocking System Stack emissions are same as Central Furnaces Stocking System corrected for differences in flow rates.

(9) Six times the value reported in Ref. [23] for Furnace Taphole Fume Collector release rate.

Activity Balance

Figure 3-19 presents a flowchart illustrating the flow of radioactivity through the Monsanto-Tennessee process. The kiln feed concentrations assumed in this figure are those reported in Reference [23] which contain some Florida ore. Thus, the quantities of radionuclides processed would be somewhat lower if only Tennesse ore was used, as is currently the case. For the nonvolatile radionuclides, essentially all of the input radioactivity can be accounted for in the slag by-product(1). A significant fraction of the input Pb-210 and Po-210, however, cannot be accounted for in the products or the airborne emissions. These materials are assumed to be volatilized in the kiln or furnace processes, filtered from the offgas stream by wet scrubber systems, and discharged to the liquid settling pond.

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(1) The total Th-230 output is listed as exceeding the total Th-230 input because of error in the radioanalytical counting procedure.

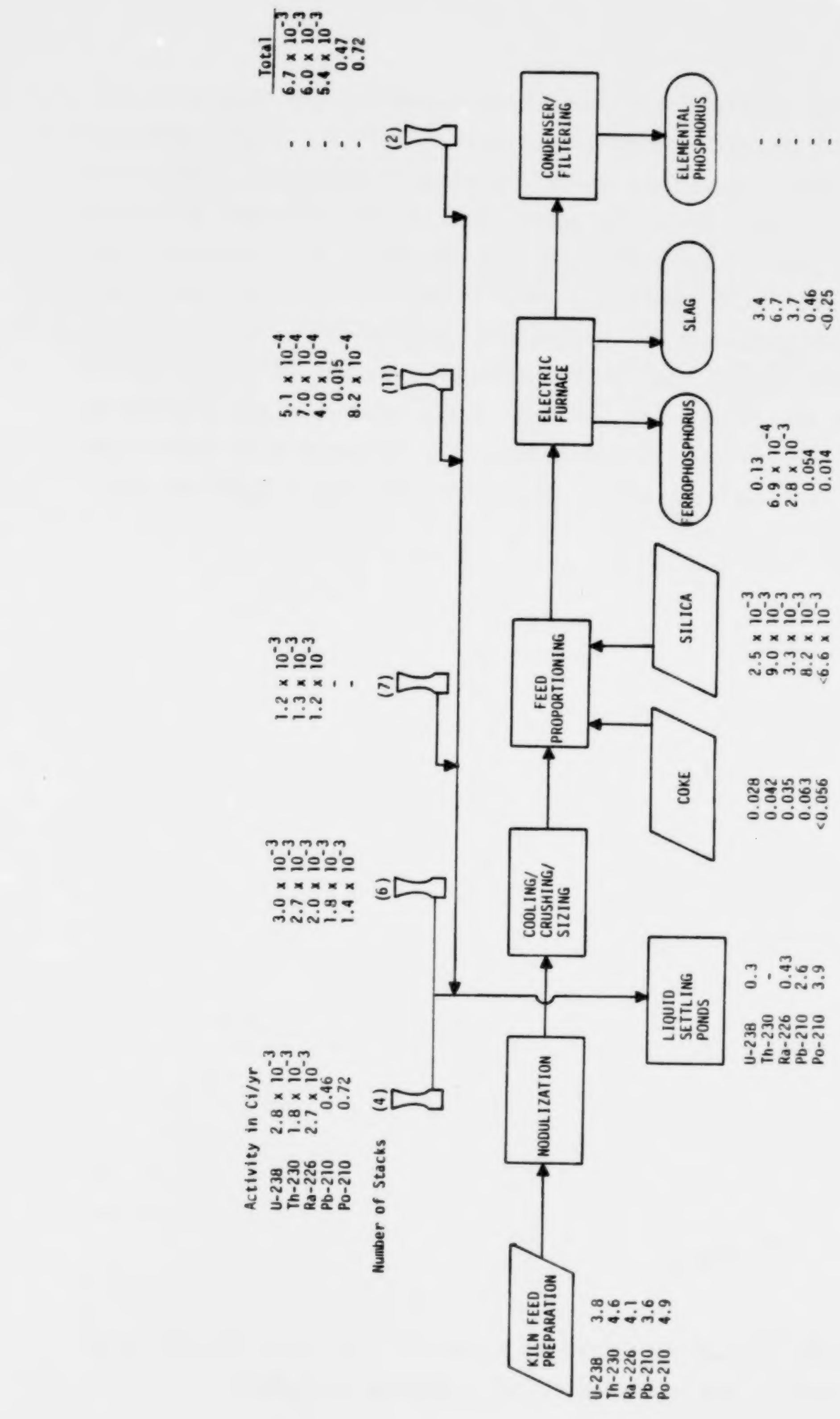
Activity in Ci/yr
U-238 2.8×10^{-3}
Th-230 1.8×10^{-3}
Ra-226 2.7×10^{-3}
Pb-210 0.46
Po-210 0.72
Number of Stacks (4)
(6)
3.0×10^{-3}
2.7×10^{-3}
2.0×10^{-3}
1.8×10^{-3}
1.4×10^{-3}
(7)
1.2×10^{-3}
1.3×10^{-3}
1.2×10^{-3}
-
-
(11)
5.1×10^{-4}
7.0×10^{-4}
4.0×10^{-4}
0.015
8.2×10^{-4}
(2)
-
-
-
-
-
Total
6.7×10^{-3}
6.0×10^{-3}
5.4×10^{-3}
0.47
0.72
KILN FEED PREPARATION
U-238 3.8
Th-230 4.6
Ra-226 4.1
Pb-210 3.6
Po-210 4.9
NODULIZATION
LIQUID SETTLING PONDS
U-238 0.3
Th-230 -
Ra-226 0.43
Pb-210 2.6
Po-210 3.9
COOLING/ CRUSHING/ SIZING
COKE
0.028
0.042
0.035
0.063
<0.056
FEED PROPORTIONING
SILICA
2.5×10^{-3}
9.0×10^{-3}
3.3×10^{-3}
8.2×10^{-3}
$<6.6 \times 10^{-3}$
ELECTRIC FURNACE
FERROPHOSPHORUS
0.13
6.9×10^{-4}
2.8×10^{-3}
0.054
0.014
SLAG
3.4
6.7
3.7
0.46
<0.25
CONDENSER/ FILTERING
ELEMENTAL PHOSPHORUS
-
-
-
-
-

Figure 3-19. Activity Balance for the Monsanto-Tennessee Plant.

3.3.6 Monsanto Plant - Soda Springs, Idaho

3.3.6.1 Monsanto-Idaho Plant Site Characterization

The Monsanto-Idaho plant is located at 111° 35' 30" longitude and 42° 41' 30" latitude in a mountainous region of southeastern Idaho. The plant is 4 km north of the town of Soda Springs at an elevation of 1829 m. It is about 1.6 km east of a small lake and 6 km northeast of the larger Alexander Reservoir and the Bear River. The plant is adjacent to state Highway 34 and is served by a railroad spur. It is just a few kilometers west of the mountainous Caribou National Forest.

The plant is in a high meadow valley containing scattered meadow areas and small lakes and ponds. A map showing the area and major points of interest is shown in Figure 3-20.

Meteorology and Air Quality

This region is semiarid, with annual rainfall averaging 31 cm. The average annual temperature is 10.5°C. Winds in this region are generally from the west or south at 4 to 5 m/s.

Demography

The plant is in Caribou county, which has a population of 8695, or 3 persons per km^2, as of the 1980 census. Actual population densities around the plant are shown in Appendix A.

Land Use

Farmland accounts for 65 percent of the total county, with 59 percent of the farmland used as rangeland. Produce grown in the county consists of protected produce (potatoes, beets, etc.) and food grains. Beef cattle and sheep are the major range animals raised. Chicken and egg production occurs on a moderate scale (1,500 laying hens in 1974). Agriculture ponds account for less than 0.02 percent of the land use of the county.

3.3.6.2 The Monsanto-Idaho Process

Phosphate ore is shipped continuously throughout the warm weather months to Monsanto by truck from the local Henry Mine. A stockpile is

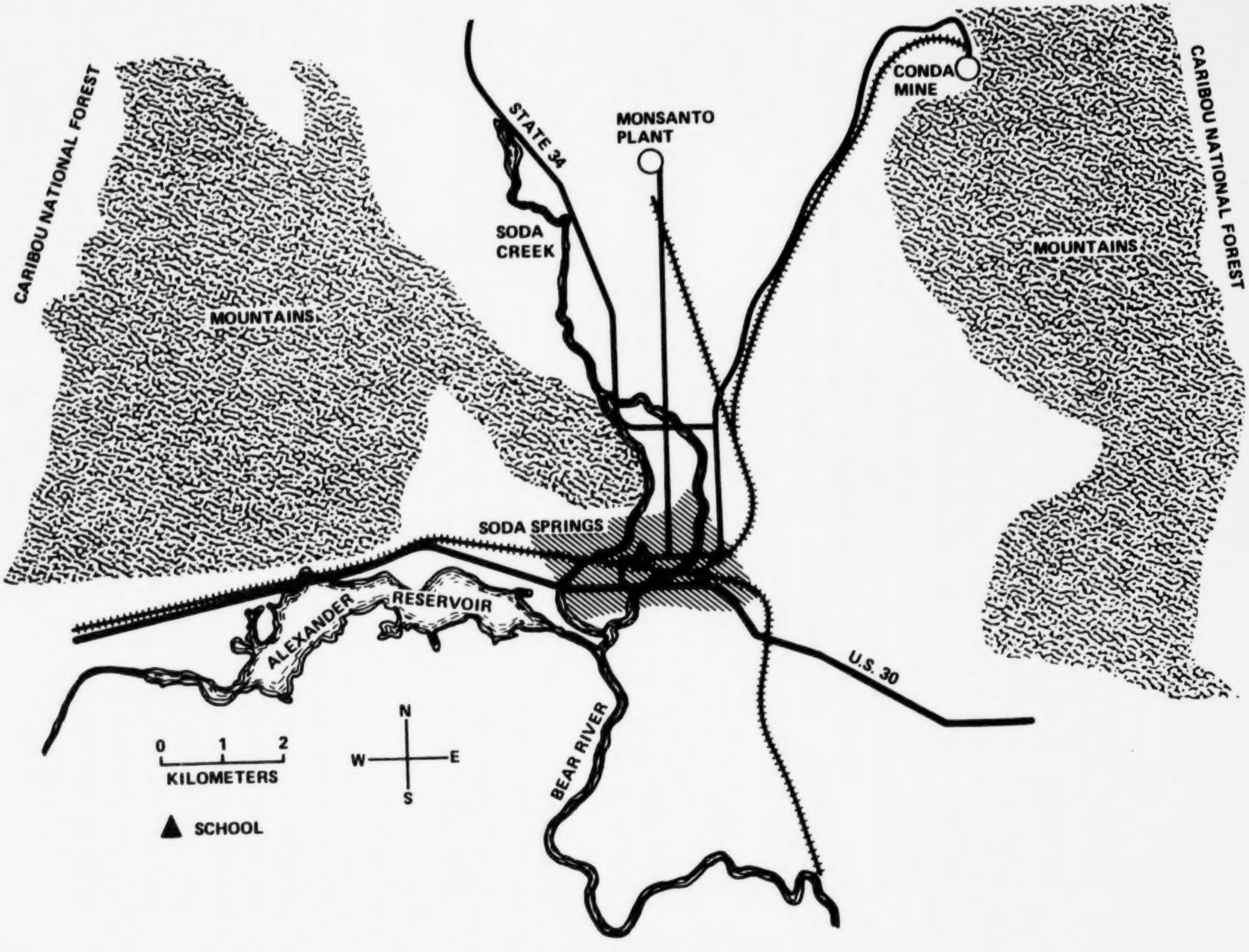
CARIBOU NATIONAL FOREST
MOUNTAINS
STATE 34
SODA CREEK
MONSANTO PLANT
CONDA MINE
MOUNTAINS
CARIBOU NATIONAL FOREST
SODA SPRINGS
ALEXANDER RESERVOIR
U.S. 30
BEAR RIVER
N
W
E
S
0
1
2
KILOMETERS
▲ SCHOOL

Figure 3-20. Monsanto-Idaho Plant Site Area.

accumulated for winter use. A schematic of the plant operation is provided as Figure 3-21.

The phosphate ore dust from the kiln is collected and recycled back to the kiln. Nodule sizing/screening reject fines are stockpiled and also recycled to the kiln. The blended ore is fed to the rotary kiln by a hooded belt conveyer. The rotary kiln produces large, stable agglomerates (nodules) that allow for proper operation of the electric reduction furnaces. The rotary kiln raises the ore temperature to its incipient melting point (about 1300°C), and the tumbling action causes the ore to agglomerate into the desired nodular form. The rotary kiln is fueled with carbon monoxide generated in the electric reduction furnace operation and supplemental coal as needed. The kiln offgas is vented into a sequential offgas treatment operation consisting of a knockout chamber, spray tower, and demister. The wet scrubber uses a lime-treated scrubbing liquor to remove fluorine, P_2O_5, and particulates.

The hot nodules from the kiln are passed through a moving grate nodule cooler and are conveyed to the nodule sizing system. The nodule sizing system consists of crushing and screening operations. Fines from the sizing operation are recycled to be mixed with the kiln feed. The nodule sizing system has an independent offgas treatment system consisting of a venturi scrubber and cyclone separator.

Following sizing, the nodular material is transferred to the proportioning building. Coke is dried and sized on site, and the sized coke is stored in bins feeding the burden scales. Washed silica is also dried on site and stored in a bin feeding the burden scales. At the burden scales, the coke, silica, and nodules are mixed using a porportioning weighing system. This mixture (burden) is moved by hooded belt conveyer to burden bins that distribute it into one of three electric arc furnaces. The burden bins are located above the furnaces and continuously feed the furnaces by gravity.

The burden scales offgas treatment system consists of a baghouse and a backup wet scrubber. A baghouse is used on the burden transfer system. The dust from the furnace feed bins is also collected using baghouses.

At this plant, Monsanto operates three electric reduction furnaces that operate at 1400 to 1800°C. The furnaces operate continuously and are

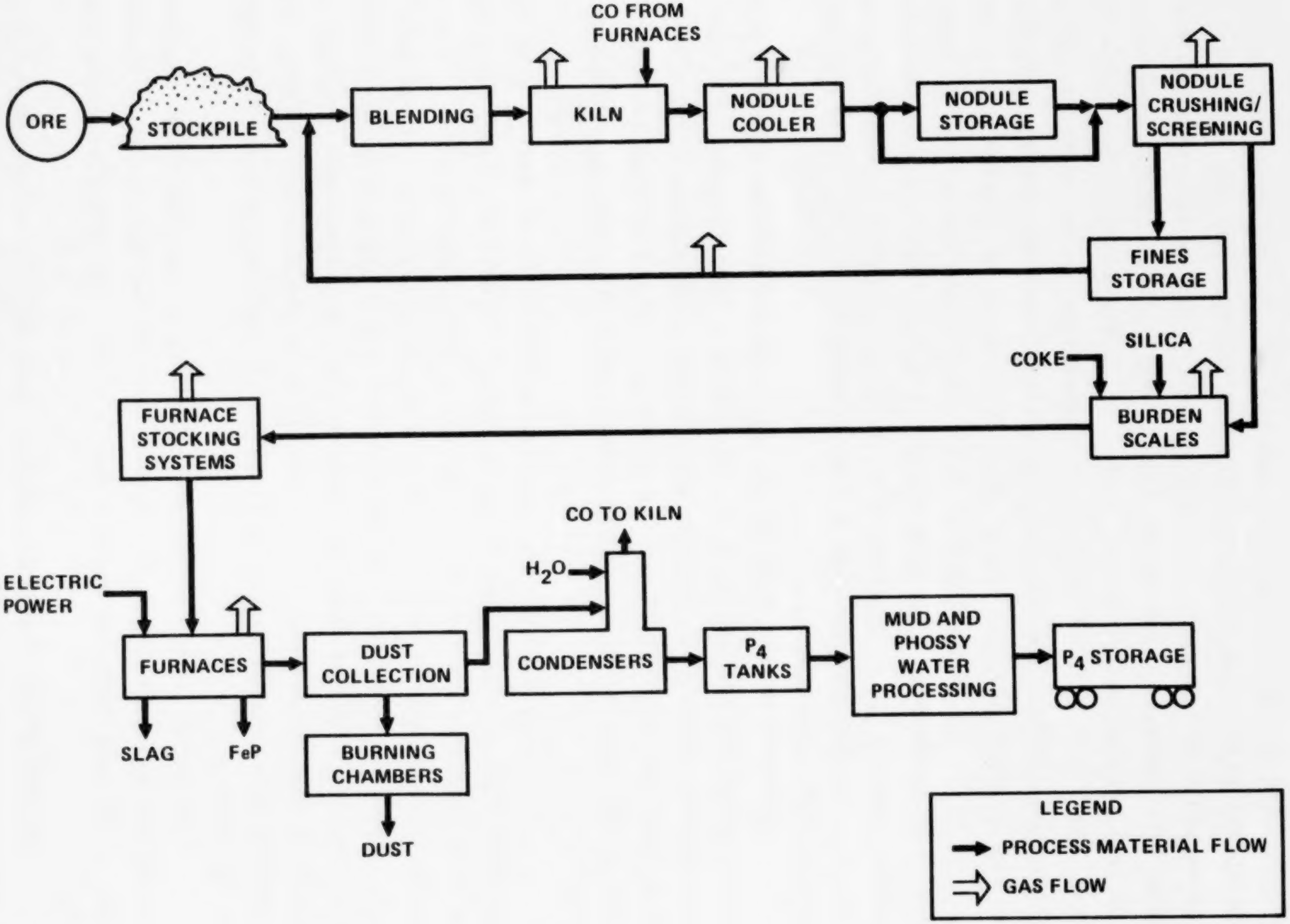
CO FROM FURNACES
ORE
STOCKPILE
BLENDING
KILN
NODULE COOLER
NODULE STORAGE
NODULE CRUSHING/ SCREENING
FINES STORAGE
COKE
SILICA
BURDEN SCALES
FURNACE STOCKING SYSTEMS
ELECTRIC POWER
FURNACES
SLAG
FeP
DUST COLLECTION
BURNING CHAMBERS
DUST
CO TO KILN
H_2O
CONDENSERS
P_4 TANKS
MUD AND PHOSSY WATER PROCESSING
P_4 STORAGE
LEGEND
PROCESS MATERIAL FLOW
GAS FLOW

Figure 3-21. Simplified Process Flow Diagram for the Monsanto-Idaho Plant.

periodically tapped to remove the molten slag and ferrophosphorus that accumulate at the bottom. Slag taps occur about 12 times per 8-hour shift per furnace and last about 20 minutes per tap. The ferrophosphorus is tapped once or twice per day. The molten slag is tapped into slag ladles that are transported and poured onto the slag storage pile at the site. The ferrophosphorus slag is collected in slag ladles, cooled, and sent to an Idaho company for vanadium recovery. The tapping offgases are collected in hooded systems and treated by a venturi scrubber and cyclone separator.

The furnace offgases, composed of mainly carbon monoxide and phosphorus, are drawn through electrostatic precipitator dust collecters where particulates are removed. The cleaned gases are then sent through water spray condensers where the gases cool and the phosphorus condenses. The condensed phosphorus is collected in tanks, sent to settling tanks for sludge and phossy water removal, and then pumped to underwater storage. The stored phosphorus is bottom loaded into water-sealed railroad cars for shipment to Monsanto chemical plants where it is combined with other elements to make various phosphate compounds.

3.3.6.3 Monsanto-Idaho Plant Feed Materials Characterization

The Monsanto-Idaho plant uses the same feed materials as the basic process plant described in Section 3.2. Table 3-31 provides the sources and typical values for the composition, quantities utilized per short ton of phosphorus produced, and the radionuclide content for the feed materials. The range of values for the typical quantity reported is estimated as ± 10 percent.

3.3.6.4 Monsanto-Idaho Plant Product Materials Characterization

The Monsanto-Idaho plant produces the same basic products as described in Section 3.2. Monsanto has made a corporate decision to store the slag product as a waste material until an industry standard or regulation providing guidelines for commercial utilization is promulgated. Table 3-32 provides the sales destination and typical values for the composition, quantities produced per short ton of elemental phosphorus produced, and the radionuclide content for the products. The range of values for the typical quantity reported is estimated as ±10 percent.

Table 3-31. Monsanto-Idaho Phosphorus Plant Feed Materials Characterization.

Characteristic	Phosphate Ore	Coke	Silica
1. Source	Henry Mine, near plant	Wyoming and other sources	Mined near plant
2. Chemical Composition, wt %(1)			
P_2O_5	27.5	-	-
SiO_2	17	3.3(2)	98.5
CaO	44	-	1.5(2)
Al_2O_3	3	1.3(2)	
Fe_2O_3	1.1	0.3(2)	
C	-	90.9 (dry(2) basis)	-

Table 3-31. Monsanto-Idaho Phosphorus Plant Feed Materials Characterization. (Continued)

Characteristic	Phosphate Ore	Coke	Silica
3. Radionuclide content, pCi/g(2)			
U-238	22	0.5	1.5
Th-230	22	0.2	1.6
Ra-226	26	0.8	1.7
Pb-210	27	2.4	0.7
Po-210	22	1.3	2.6
4. Feed material utilization, ton/ton P_4 produced(3)	10.5	1.3	2.6
5. Electrical power, kWh/short ton P_4 produced(1)	13,200		

(1) Data presented to SAI staff at November 3, 1982, meeting at Monsanto's Elemental Phosphorus Plant in Soda Springs, Idaho.

(2) Assumed identical to that used at FMC Plant.

(3) SAI engineering estimates.

Table 3-32. Monsanto-Idaho Phosphorus Plant Product Materials Characterization.

Characteristic	Phosphorus	Slag	Ferrophosphorus	Electrostatic Precipitator Dust
1. Sales destination(1)	Monsanto chemical plants	Stored on site	Local Idaho company	Local Idaho company
2. Utilization(1)	Chemicals production	-	Vanadium recovery	Fertilizer
3. Chemical Composition, wt %(1)				
SiO_2	-	44	-	
CaO	-	44	-	
Al_2O_3	-	6	-	
Fe_2O_3	-	0.4	-	
P_2O_5	-	1.0	-	27(2)
P	>99.9	-	30	
Fe	-	-	54	
V	-	-	8	
Cr			7	

Table 3-32. Monsanto-Idaho Phosphorus Plant Product Materials Characterization. (Continued)

Characteristic	Phosphorus	Slag	Ferrophosphorus	Electrostatic Precipitator Dust
4. Radionuclide content, pCi/g (3)				
U-238	-	25	19	71
Th-230	-	26	0.4	24
Ra-226	-	32	0.3	13
Pb-210	-	11	1.1	52
Po-210	-	16	0.6	440
5. Production, ton/ton P_4 produced (1)	1.0	8.4	0.16	0.06

(1) Data presented to SAI staff at November 3, 1982, meeting at Monsanto's Elemental Phosphorus Plant in Soda Springs, Idaho.

(2) Assumed similar to FMC "prills".

(3) Assumed identical to materials at FMC plant.

3.3.6.5 Monsanto-Idaho Plant Waste Materials

The Monsanto-Idaho plant generates only minor quantities of waste materials. All slurry solids and phossy water are recycled. Baghouse dust collection solids are landfilled. Slag is stockpiled on site for either future sale or disposal. Scrap metal and other plant wastes are cleaned and sold for scrap at salvage values except for a very small quantity of construction rubble that is disposed of on site.

3.3.6.6 Monsanto-Idaho Process Airborne Emissions and Sources Characterization

A key objective of this study was to identify and characterize the major airborne emission points. To fulfill this objective, plant operating permits at the Idaho Department of Health and Welfare - Division of Environment in Boise, Idaho, were obtained and a literature search was conducted. In addition, the plant was toured on November 3, 1982, and key staff were interviewed.

Emission points were divided into point sources, vents, and fugitive sources. This section only reports emission sources and characterizes the emissions. The related air pollution control equipment is described in Chapter 4.

Point Sources

Table 3-33 lists the air pollution sources, emission points, and control equipment (characterized in Chapter 4). Point source emissions are generally continuous.

Vents

Table 3-34 lists the vents, including emergency vents, air pollution sources, emission points, and control equipment (characterized in Chapter 4). Vent emissions are intermittent.

Fugitive Emission Sources

The fugitive emission sources are the slag pit, handling and stockpile areas; miscellaneous furnace leaks; plant roads; and phosphate ore stockpile. Each of these areas is discussed below.

Table 3-33. Point Sources of Airborne Emissions for the Monsanto-Idaho Plant.

Air Pollution Source	Emission Points	Control Equipment
Rotary kiln	Kiln scrubber stack	Spray tower scrubber, demister
Nodule cooler	Nodule cooler stack	Spray tower scrubber, demister
Nodule sizing system	Nodule sizing system stack	Venturi scrubber, cyclone separator
Coke and silica hopper	Coke and silica hopper	Baghouse
Coke handling and sizing system	Coke handling and sizing system	Baghouse
Coke bunker	Coke bunker system stack	Baghouse
Coke/silica drying system	Coke/silica drying stack	Spray tower scrubber
Silica handling system (scaleroom)	Scaleroom stack	Baghouse
Feed transfer and stocking system	Burden transfer system stack	Baghouse
	#7 burden bin stack	Baghouse
	#8 burden bin stack	Baghouse
	#9 burden bin stack	Baghouse
#7 furnace tapping system	#7 furnace taphole fume stack	Venturi scrubber, cyclonic separator
#8 furnace tapping system	#8 furnace taphole fume stack	Venturi scrubber, cyclonic separator
#9 furnace tapping system	#9 furnace taphole fume stack	Venturi scrubber, cyclonic separator
Furnace offgas systems	#7,8 CO flare stacks #9 CO flare stack	Individual electrostatic precipitator, water spray tower condenser system treating each furnace offgas

Table 3-34. Vents and Emergency Vents for the Monsanto-Idaho Plant.

Air Pollution Source	Emission Point	Control Equipment
#7 furnace pressure seal	#7 vent stack	Water sprays in the stack
#8 furnace pressure seal	#8 vent stack	Water sprays in the stack
#9 furnace pressure seal	#9 vent stack	Water sprays in the stack

- Slag Handling and Stockpile

  The slag handling and stockpile areas are defined as fugitive emission sources. The molten slag tapped from the furnaces flows by gravity into a ladle and is transferred in its molten state by front-end loaders that haul it to the slag storage pile. The dumping of the molten slag raises very small amounts of water vapor and P_2O_5 fumes during wet weather. After cooling, the pile becomes nearly monolithic in structure and is not a source of fugitive dust.

- Miscellaneous Furnace Leaks

  Each furnace has three carbon electrodes which are continuously fed into the furnace. To prevent furnace gas from leaking around the electrodes, they are equipped with Monsanto-designed seals. However, periodic pressure surges caused by bridging and collapse of material in the furnace allows very small quantities of gases to leak into the building.

- Plant Roads

  The plant roads are not paved and travel on these roads causes fugitive dust emissions. Water spraying of the roads during dry periods to control fugitive dust is standard practice.

- Ore Stockpile

  The ore stockpiles are not generally a significant source of fugitive dust because of the moisture content of the ore. However, during dry conditions, dust can be generated from the stockpiles.

Key Sources of Radionuclide Emissions

The estimated annual particulate radionuclide emissions to air from the Monsanto-Idaho plant are summarized in Table 3-35. These estimates, unlike the Monsanto-Tennessee plant, are not based directly on actual radionanalytical results. The Pb-210 and Po-210 emissions have been estimated from the Monsanto-Tennessee radioanalytical results factored to cor-

Table 3-35. Stack and Emission Data for the Monsanto-Idaho Elemental Phosphorus Plant.

Source	Stack Geometry		Stack Gas Characteristics				Particulate Emissions		Radionuclide Emissions pCi/s (Ci/yr)				
	Height (m)	Diameter (m)	Flow (ACMM)	Exit Velocity (m/s)	Exit Temperature C° (K°)	Heat Release (cal/s)	(g/m^3)	(g/s)	U-238	Th-230	Ra-226	Pb-210	Po-210
#5 kiln(1)	30.5	6.1	8592	4.9	60 (333)	1.8×10^6	0.003	0.46	10	10	12	100,000	96,000
Grate cooler(2)	36.9	3.9	4874	6.8	48 (321)	8.1×10^5	0.009	0.07	2.4	1.9	2.7	3.0	0.8
Nodule sizing area(2)	24.7	3.6	4092	6.7	42 (315)	5.9×10^5	0.001	0.09	3.1	2.4	3.5	3.9	1.1
Fines reclaim nodule sizing area				No Stack Data			-	-	-	-	-	-	-
Coke handling crusher/screens(3)	9.1	0.9	699	18.3	AMB	0	0.001	0.01	0.005	0.002	0.008	0.02	0.01
Coke bunker(3)	9.1	0.9	699	18.3	AMB	0	0.001	0.01	0.005	0.002	0.008	0.02	0.01
Silica bunker(4)	9.1	0.9	699	18.3	AMB	0	0.001	0.01	0.02	0.02	0.02	0.01	0.03
Rotary dryer	18.3	1.2	1221	18.0	31 (304)	1.2×10^5	0.000	0.004	-	-	-	-	-
Scale room(2)	16.8	0.7	774	33.5	30 (303)	7.2×10^4	0.005	0.06	2.0	1.6	2.3	2.6	0.7
Transfer points/ furnace belt(2)				No Stack Data			-	-	-	-	-	-	-
Burden bin #7(2)				No Stack Data			-	-	-	-	-	-	-
Burden bin #8(2)				No Stack Data			-	-	-	-	-	-	-
Burden bin #9(2)				No Stack Data			-	-	-	-	-	-	-
Furnace #7 taphole(5)	14.0	0.9	729	19.1	45 (318)	1.2×10^5	0.001	0.01	-	-	-	2800	950
Furnace #8 taphole(5)	36.0	0.9	748	19.6	45 (318)	1.2×10^5	0.001	0.01	-	-	-		
Furnace #9 taphole(5)	24.7	0.9	748	19.6	45 (318)	1.2×10^5	0.000	0.003	-	-	-		
Condenser CO flare	-	-	-	-	-	-	-	-	-	-	-	-	-
Totals									18 (5.7E-4)	16 (5.0E-4)	21 (7.6E-4)	100,000 (3.2)	97,000 (3.1)

(1) Assumes radionuclide concentration of particulate emissions same as that for PO_4 ore for U-238, Th-230, and Ra-226. For Pb-210 and Po-210 emissions, estimate is based on Monsanto-TN kiln emissions factored by differences in radionuclide concentrations in kiln feed, and mass flow rates.

(2) Assumes radionuclide concentration of particulate emissions same as that for nodules (estimated by ore:nodule ratios from Monsanto - TN plant).

(3) Assumes radionuclide concentration of particulate emissions are same as that for coke.

(4) Assumes radionuclide concentration of particulate emissions are same as that for silica.

(5) Estimate based on Monsanto - TN, effluent data factored by radionuclide concentrations in nodules (flow rates and ton/yr nodules are nearly equal).

rect for differences in mass flow rates and radionuclide concentrations. The nonvolatile emissions estimates are based on assumed radionuclide concentrations of particulate emissions. The results of these assessments indicate that Pb-210 and Po-210 are the only significant radionuclide emissions. About 100,00 pCi/s (3.15 Ci/yr) of Pb-210 and 97,000 pCi/s (3.05 Ci/yr) of Po-210 are released from the kiln stack, while about 2800 pCi/s (0.088 Ci/yr) of Pb-210 and 950 pCi/s (0.030/yr) of Po-210 are released from the furnace taphole stacks. Only minor quantities of nonvolatile radionuclides are emitted from this plant, and these emissions occur mainly from the kiln, nodule grate cooler, and nodule sizing area stacks.

Data are not available for estimated Rn-222 releases from the Monsanto-Idaho plant. However, this release is estimated at 50 Ci/yr using Rn-222 release data from the Monsanto-Tennessee plant modified by the difference in quantities of Ra-226 processed annually.

Activity Balance

The flow of radioactivity through the Monsanto-Idaho plant process is illustrated in Figure 3-22. Over 90 percent of the input U-238, Th-230, and Ra-226 is accounted for in the output slag. Volatilization of lead and polonium is evidenced by the depleted Pb-210 and Po-210 concentrations in the slag. A significant amount of input Po-210 (>10 percent) is contained in the dust recovered from the electrostatic precipitators, which is sold as a product. Of the input activity, approximately 10 percent of the U-238 and Th-230, 5 percent of the Ra-226, 50 percent of the Pb-210, and 10 percent of the Po-210 are unaccounted for in products and air emissions and are presumably deposited by scrubber and condenser effluents into phossy water settling ponds.

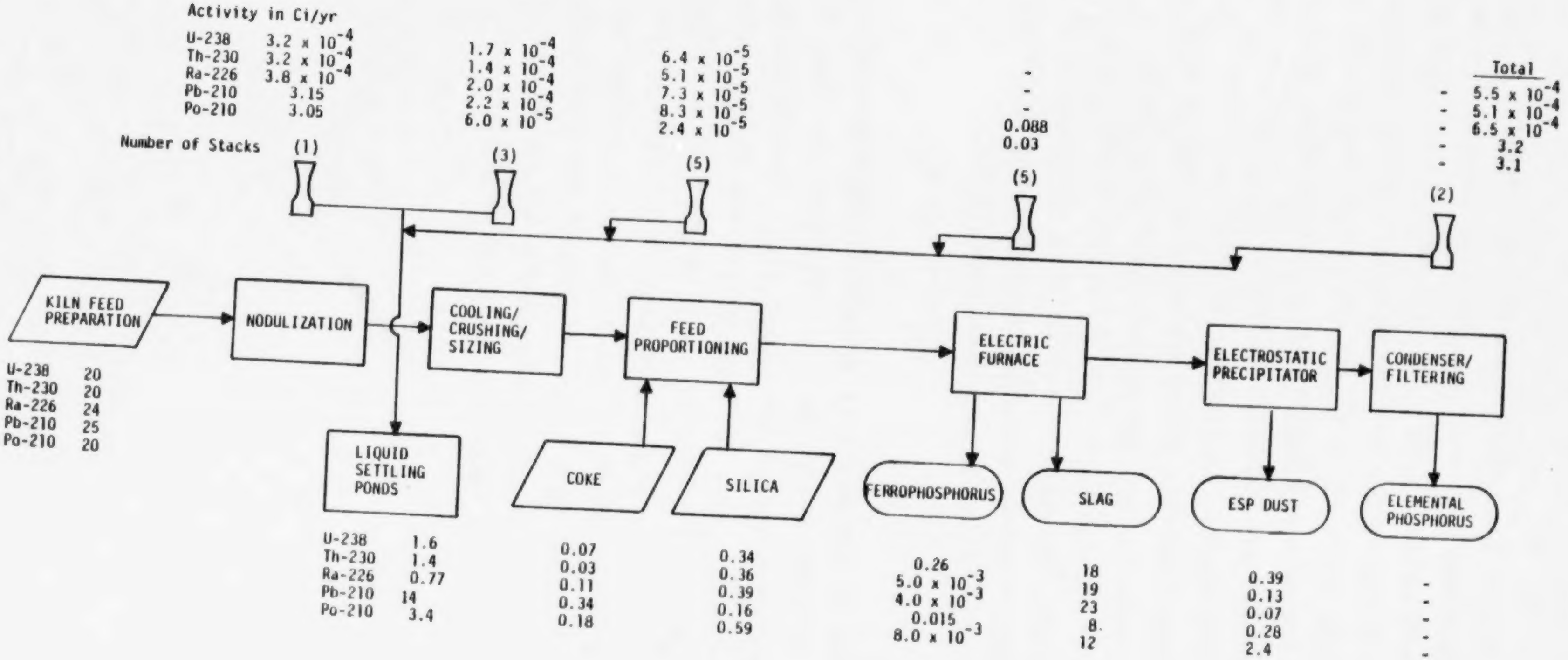
Activity in Ci/yr
U-238 3.2 x 10^-4
Th-230 3.2 x 10^-4
Ra-226 3.8 x 10^-4
Pb-210 3.15
Po-210 3.05
Number of Stacks
(1)
1.7 x 10^-4
1.4 x 10^-4
2.0 x 10^-4
2.2 x 10^-4
6.0 x 10^-5
(3)
6.4 x 10^-5
5.1 x 10^-5
7.3 x 10^-5
8.3 x 10^-5
2.4 x 10^-5
(5)
-
-
-
0.088
0.03
(5)
Total
- 5.5 x 10^-4
- 5.1 x 10^-4
- 6.5 x 10^-4
- 3.2
- 3.1
(2)
KILN FEED PREPARATION
U-238 20
Th-230 20
Ra-226 24
Pb-210 25
Po-210 20
NODULIZATION
COOLING/ CRUSHING/ SIZING
FEED PROPORTIONING
ELECTRIC FURNACE
ELECTROSTATIC PRECIPITATOR
CONDENSER/ FILTERING
LIQUID SETTLING PONDS
U-238 1.6
Th-230 1.4
Ra-226 0.77
Pb-210 14
Po-210 3.4
COKE
0.07
0.03
0.11
0.34
0.18
SILICA
0.34
0.36
0.39
0.16
0.59
FERROPHOSPHORUS
0.26
5.0 x 10^-3
4.0 x 10^-3
0.015
8.0 x 10^-3
SLAG
18
19
23
8
12
ESP DUST
0.39
0.13
0.07
0.28
2.4
ELEMENTAL PHOSPHORUS
-
-
-
-
-

Figure 3-22. Activity Balance for the Monsanto-Idaho Plant.

3.3.7 Mobil Chemical Company Plant - Pierce, Florida

The Mobil Chemical elemental phosphorus plant is not currently operating. No projected restart date is available.

3.3.7.1 Mobil Chemical Plant Site Characterization

The Mobil Chemical elemental phosphorus plant is located at longitude 81° 57' 25" and latitude 27° 49' 50". It is 1 km east of Pierce, Florida, and 5 km south of the town of Mulberry. The plant has tailings ponds 180° around it to the north and small lakes and marshlands to the south. It is served by a railroad line and is 1.5 km east of State Highway 37. An agricultural chemical plant is located in Pierce, and many strip mining operations occur in the general vicinity. A map indicating the general area and major features is shown in Figure 3-23.

Meteorology and Air Quality

The average annual rainfall for the area is 135 cm and the average annual temperature is 22.5°C. Winds in the area are primarily from the west at 2 to 5 m/s.

Demography

The plant is in Polk county. The 1980 census indicated a population of 321,652 for the county, or about 68 persons per km^2. Actual population distributions around the plant are shown in Appendix A.

Land Use

Sixty-seven percent of the county is agricultural land with only 0.03 percent of the county land devoted to agricultural ponds. About 0.02 percent of the agricultural land is used for leafy vegetables and exposed produce (fruits and tomatoes) and 13 percent is used to produce protected produce (primarily citrus). Twenty-eight percent of the agricultural land is used as range land. Beef cattle and chickens are the primary animals raised. Eighteen percent of the county is wetland, and 12.5 percent is land used for strip mines, quarries, etc.

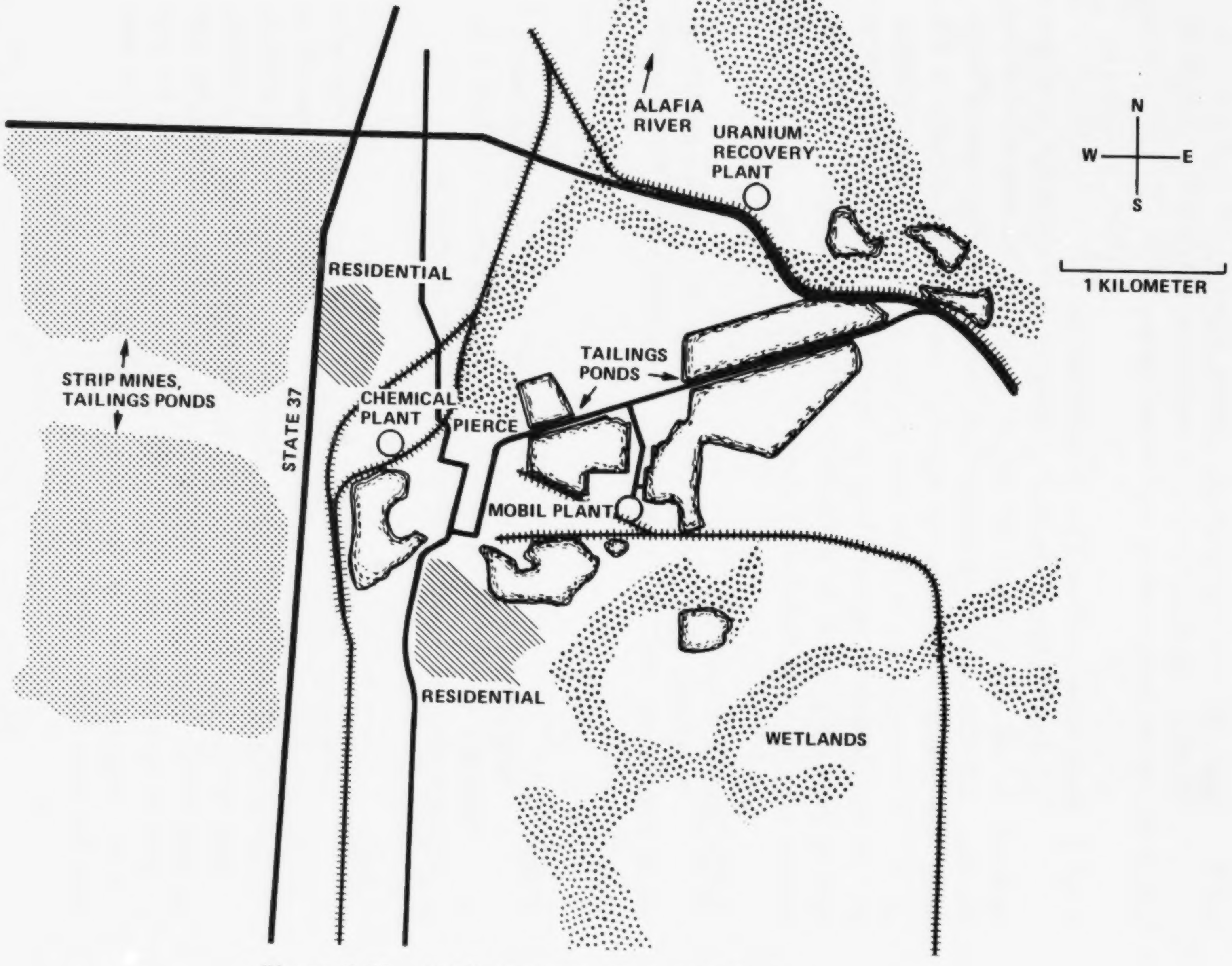
ALAFIA RIVER
URANIUM RECOVERY PLANT
N
W
E
S
1 KILOMETER
RESIDENTIAL
TAILINGS PONDS
STRIP MINES, TAILINGS PONDS
CHEMICAL PLANT
PIERCE
STATE 37
MOBIL PLANT
RESIDENTIAL
WETLANDS

Figure 3-23. Mobil Chemical Plant Site Area.

3.3.7.2 The Mobil Chemical Plant Process

Phosphate pebble rock ore is shipped throughout the year to the plant by truck and rail from local Florida phosphate mines. Only a small stockpile is maintained on site. When functioning, the plant operates 24 hours per day, 365 days per year. A schematic of the plant operating areas is provided in Figure 3-24.

The wet ore is transferred to a rock dryer and heated by burning carbon monoxide recycled from the furnaces and auxiliary oil (as needed). The 149°C offgas from the rock dryer is treated sequentially by twin parallel cyclones, a venturi scrubber, and a cyclone separator. Cyclone dust is sent to the briquetting system feed bin for blending. Some dried rock is sent directly to the fuel proportioning area.

Proportions of dry phosphate rock, recycled phosphate fines, and dust are treated with phosphoric acid and formed into briquettes. The briquettes are moved by belt conveyer to a sizing screen where undersized material is recycled to the briquetting system feed hoppers. The properly sized briquettes are sent through a traveling grate calciner for drying and sintering. The calciner is heated to about 177°C by burning carbon monoxide. Offgases from the calciner are sequentially treated by twin parallel cyclones, a wet scrubber, and a series of two wet cyclone separators. Cyclone dust is recycled to the briquetting system feed bin.

The sintered briquettes are moved from a storage hopper by truck to an elevator for vertical transfer to the briquette sizing area. The briquettes are screened and the undersized material is recycled to the briquetting system feed bin. Properly sized briquettes are then blended with dried rock (directly from the rock dryer), sized coke, and silica via a feed proportioning belt.

The coke sent to the feed proportioning area is dried and sized on site. The silica is brought to the site by railcar principally from North Carolina suppliers (90 percent) and Alabama.

The furnace feed mixture is transferred by belt conveyer to the furnace feed bin and gravity fed to one of two electric reduction furnaces that operate at 1400 to 1800°C. The furnaces operate continuously and are periodically tapped to remove the molten slag and ferrophosphorus that accumulate at the furnace bottom. The furnaces are tapped to remove slag

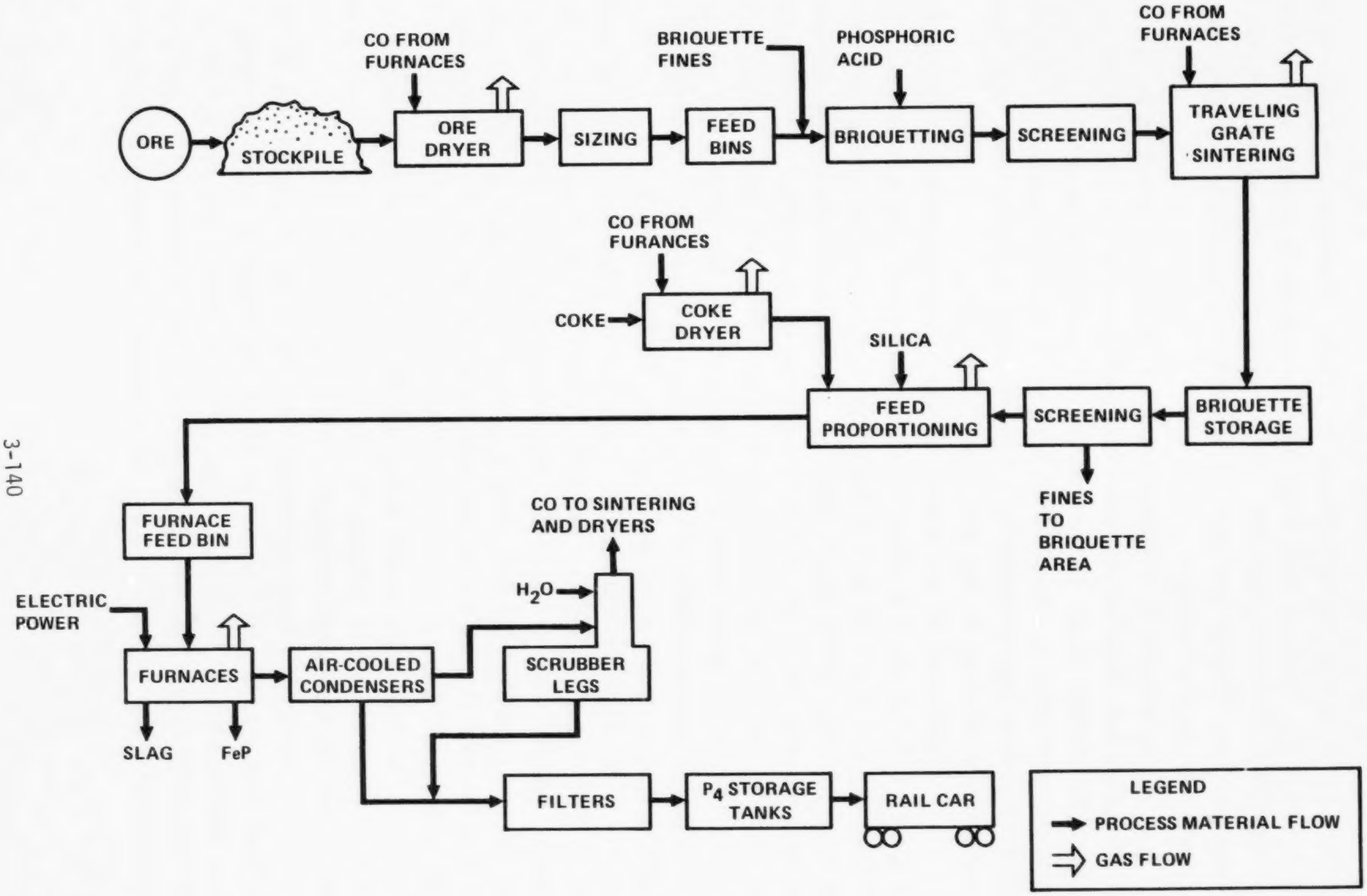
ORE
STOCKPILE
CO FROM FURNACES
ORE DRYER
SIZING
FEED BINS
BRIQUETTE FINES
PHOSPHORIC ACID
BRIQUETTING
SCREENING
CO FROM FURNACES
TRAVELING GRATE SINTERING
CO FROM FURANCES
COKE
COKE DRYER
SILICA
FEED PROPORTIONING
SCREENING
BRIQUETTE STORAGE
FINES TO BRIQUETTE AREA
FURNACE FEED BIN
CO TO SINTERING AND DRYERS
H_2O
ELECTRIC POWER
FURNACES
AIR-COOLED CONDENSERS
SCRUBBER LEGS
SLAG
FeP
FILTERS
P_4 STORAGE TANKS
RAIL CAR
LEGEND
PROCESS MATERIAL FLOW
GAS FLOW

Figure 3-24. Simplified Process Flow Diagram for the Mobil Chemical Plant.

every 30 minutes and once every 8 hours to remove the ferrophosphorus. Dust and P_2O_5 vapors generated during tapping operations of each furnace are captured in a hood system and sequentially routed through separate venturi scrubbers to a common cyclone separator before venting through a stack. The slag and ferrophosphorus taps are poured into a slag cooling pit adjacent to the furnace building. After cooling, the slag and ferrophosphorus are sent to a crushing and screening operation. During belt conveyer transfer of slag to the crushing operation, operating personnel hand sort ferrophosphorus from the slag. The crushed slag is sold and shipped directly to a company located adjacent to the plant for use as an aggregate. The ferrophosphorus is sent to the same company for subsequent sale to heavy metal recovery plants.

Furnace offgases, mainly phosphorus and CO, are drawn off. The phosphorus is condensed by passing it over water in a series of air-cooled condensers followed by two steps of water spray tower scrubbing. The cooled carbon monoxide is routed to the rock dryer, coke dryer, and traveling grate calciner for use as fuel. The liquid phosphorus is filtered and pumped to on-site storage tanks before ultimate rail shipment to other Mobil Chemical plants. (Small amounts, less than 10 percent, are shipped in barrels by truck.)

3.3.7.3 Mobil Chemical Plant Feed Materials Characterization

The Mobil Chemical plant uses the same feed materials as the basic process plant described in Section 3.2. These are phosphate pebble rock ore, coke, and silica. Table 3-36 provides the sources and typical values for the composition, quantities utilized per ton of phosphorus produced, and the radionuclide content for these feed materials. The range of values for the typical quantity reported is estimated as ±10 percent.

3.3.7.4 Mobil Chemical Plant Product Materials Characterization

The Mobil Chemical plant produces the same basic products as described in Section 3.2. Table 3-37 provides the sales destination and typical values for the composition, quantities produced per ton of elemental phosphorus produced, and the radionuclide content of the products. The range of values for the typical quantity reported is estimated as ±10 percent.

Table 3-36. Mobil Chemical Phosphorus Plant Feed Materials Characterization.

Characteristic	Phosphate Ore		Coke	Silica
1. Source(1)	Local Florida mines		Various suppliers	North Carolina and Alabama
2. Chemical Composition, wt%(1)				
P_2O_5	28.7		-	-
SiO_2	8.2		3.3(2)	97.0(2)
CaO	43.8		-	0.3(2)
Al_2O_3	1.5		1.3(2)	1.5(2)
Fe_2O_3	2.5		0.3(2)	1.0(2)
C			>85 (dry basis)	-
3. Radionuclide Content, pCi/g(1)	Wet Rock	Dry Rock		
U-238	45	52	3.0	0.6
Th-230	45	52	3.0	0.6
Ra-226	39	65	3.0	1.2
Pb-210	41	49	1.3	0.9
Po-210	49	68	0.8	0.8

Table 3-36. Mobil Chemical Phosphorus Plant Feed Materials Characterization. (Continued)

Characteristic	Phosphate Ore	Coke	Silica
4. Feed Material Utilization, ton/ton P_4 produced (2)	13.7	1.4	0.8
5. Electrical Power, kWh/short ton P_4 produced(1)	13,000		

(1) Data presented to SAI staff at October 28-29, 1982, meeting at Mobil Chemical Elemental Phosphorus plant in Pierce, Florida.

(2) SAI engineering estimates based on data from other southeastern plants.

Table 3-37. Mobil Chemical Phosphorus Plant Product Materials Characterization.

Characteristic	Phosphorus	Slag	Ferrophosphorus
1. Sales Destination(1)	Mobil Chemical plants	Local company, adjacent to site	Local company, adjacent to site
2. Utilization(1)	Chemicals production	Aggregate	Vanadium, metal recovery
3. Chemical Composition, wt%(1)			
SiO_2	-	42.5	-
CaO	-	47.8	-
AlO_3	-	5.5(2)	-
Fe_2O_3	-	0.5(2)	-
P_2O_5	-	2.0	-
P	>99.8	-	26
Fe	-	-	67(2)
V	-	-	3.0(2)
Cr	-	-	0.25(2)

Table 3-37. Mobil Chemical Phosphorus Plant Product Materials Characterization. (Continued)

Characteristic	Phosphorus	Slag	Ferrophosphorus
4. Radionuclide Content, pCi/g(1)			
U-238	--	54	88
Th-230	--	54	88
Ra-226	--	67	18
Pb-210	--	6.3	12
Po-210	9.0	0.8	0.7
5. Production, ton/ton P_4 produced(1)	1.0	8.6	0.10

(1) Data presented to SAI staff at October 28-29, 1982, meeting at Mobil Chemical's Elemental Phosphorus Plant in Pierce, Florida.

(2) SAI engineering estimates based on data from other southeastern plants.

3.3.7.5 Mobil Chemical Plant Waste Materials

The Mobil Chemical plant has a minor quantity of waste materials. Only the phossy water and sludge remain on site in appreciable quantities. The phossy water and the plant scrubber sludge residues are recycled.

Used furnace brick and scrap metal are decontaminated as necessary and sold for scrap at salvage value. A small amount of these materials are sent to an on-site landfill.

3.3.7.6 Mobil Chemical Process Airborne Emissions and Sources Characterization

A key objective of this study was to identify and characterize the major airborne emissions points. To fulfill this objective, plant operating permits at the Florida State Department of Environmental Regulation in Tampa, Florida, were obtained and a literature review was conducted. In addition, the plant was toured October 28 and 29, 1982, and key staff were interviewed.

Emission points were divided into point sources, vents, and fugitive sources. This section only reports on emission sources and characterizes the emissions. The related air pollution control equipment is described in Chapter 4.

Point Sources

Table 3-38 lists the air pollution sources, emission points, and control equipment (characterized in Chapter 4). Point source emissions are generally continuous.

Vents

Table 3-39 lists the vents including emergency vents, air pollution sources, emission points, and the control equipment (characterized in Chapter 4). Vent emissions are intermittent.

Fugitive Sources

The fugitive emission sources are the slag pit, handling and stockpile areas; miscellaneous furnace leaks; plant roads; and phosphate stockpiles. Each of these areas is discussed below.

Table 3-38. Point Sources of Airborne Emissions for the Mobil Chemical Plant.

Air Pollution Source	Emission Points	Control Equipment
Rock drying system	Rock dryer stack	Parallel cyclones, venturi scrubber, cyclone separator
Traveling grate calciner system	Calciner system stack	Parallel cyclones, wet scrubber leg, series of two wet cyclone separators
Feed proportioning area	Feed proportioning area stack	Baghouse
Coke drying, sizing, and handling	Coke system stack	Rotoclone scrubber with tailgas scrubber
#2 and #3 furnace slag and ferrophosphorus tapping	Taphole fume stack	Parallel venturi scrubbers, cyclone separator
#2 and #3 furnace offgas treatment system	CO flare stack	Air-cooled condensers, two vertical spray scrubbers in series

Table 3-39. Vents and Emergency Vents for the Mobil Chemical Plant.

Air Pollution Source	Emission Points	Control Equipment
Furnace ESP explosion relief vents (ERV)	#2 furnace ERV	-
	#3 furnace ERV	-
Furnace pressure relief system (PRV)	#2 furnace PRV	-
	#3 furnace PRV	-
Elevated CO flare	#2 furnace CO flare	
	#3 furnace CO flare	-
Calciner CO flare	Calciner CO flare	-

- Slag Pit, Handling and Stockpile

  The slag pit and handling and stockpile areas are defined as fugitive emission sources. The molten slag tapped from the furnaces flow by gravity into a cooling pit located adjacent to the furnace building. The cooled and fractured slag is recovered by front-end loaders and hauled to the slag sizing system. The cooling, digging, hauling, and sizing raises clouds of water vapor, dust, and P_2O_5 fumes.

- Miscellaneous Furnace Leaks

  Each furnace has three carbon electrodes that are continuously fed into the furnace. To prevent furnace gas from leaking aound the electrodes, they are equipped with seals. However, periodic pressure surges caused by bridging and collapse of material in the furnace allows gases to leak into the building.

- Plant Roads

  The plant roads are not paved and travel on these roads causes fugitive dust emissions.

- Ore Stockpile

  The ore stockpiles are not generally a problem because of the moisture content of the ore. However, during dry conditions, dust can be generated from the stockpiles.

Key Sources of Radionuclide Emissions

The estimated annual particulate radionuclide emissions from the Mobil Chemical plant are summarized in Table 3-40. Despite the high radionuclide concentrations of Florida phosphate rock, these emissions are relatively low because of the low volume of ore processed and because the briquetting and sintering process used in this plant does not subject the ore to temperatures sufficiently high to volatilize lead and polonium. These radionuclides, however, are volatilized in the electric arc furnace and about 400 pCi/s (0.013 Ci/yr of each) are emitted during tapping operations. The principal sources of particulate emissions include the rock

Table 3-40. Stack and Emission Data for the Mobil Chemical Elemental Phosphorus Plant.

Source	Stack Geometry		Stack Gas Characteristics				Particulate Emissions		Radionuclide Emissions pCi/s (Ci/yr)				
	Height (m)	Diameter (m)	Flow (ACMM)	Exit Velocity (m/s)	Exit Temperature C° (K°)	Heat Release (cal/s)	(g/m^3)	(g/s)	U-238	Th-230(1)	Ra-226	Pb-210	Po-210
Rock dryer(2)	30.5	1.3	736	9.2	46 (319)	8.3×10^4	0.05	0.60	31	31	39	29	41
Traveling grate sintering(3)	25.6	2.1	1825	8.8	49 (322)	2.3×10^5	0.04	1.30	61	61	73	52	77
Feed proporting area(3)	15.3	0.9	1132	29.6	52 (325)	6.2×10^3	0.06	1.07	50	50	60	43	63
Coke dryer(4)	18.3	0.8	393	13.0	49 (322)	4.9×10^4	0.14	0.93	2.8	2.8	ND(5)	1.2	-
Furnace tapholes(6)	29.3	2.1	1854	8.9	34 (307)	1.1×10^5	0.04	1.20	-	-	-	400	400
									145 (0.0046)	145 (0.0046)	172 (0.0054)	525 (0.017)	581 (0.018)

(1) No data for Th-230; assumes emissions are same as U-238.

(2) Assumes radionuclide concentration of particulate emissions same as that for dry PO_4 rock [24].

(3) Assumes radionuclide concentration of particulate emissions same as that for briquettes [24].

(4) Assumes radionuclide concentration of particulate emissions same as that for coke.

(5) ND = Not detected.

(6) Assumes average stack concentration of 13 pCi/m^3 for Po-210 [24], and a Pb-210:Po-210 ratio of 1.

dryer, the briquetting/sintering operations, and the feed proportioning area stacks. Collectively, these sources account for essentially all the U-238, Th-230, and Ra-226 emissions.

Data are not available on the quantities of Rn-222 released annually from the Mobil Chemical process. Based on data obtained at other plants, an annual release of 3 to 4 Ci of Rn-222 is estimated.

Increased levels of uranium series radionuclides have been detected in soil samples downwind of the plant [24]. Since these radionuclides appear to be in equilibrium and their levels decrease with depth, they probably result from plant emissions. Much of this deposition probably results from wind transport of dust from fugitive phosphate rock dust sources.

Activity Balance

The flow of radioactivity through the Mobil Chemical plant process is illustrated in Figure 3-25. The nonvolatile radionuclides are nearly all accounted for in the output slag. The Pb-210 and Po-210 content of the slag, however, has been depleted by the furnace process. Since only minor quantities of these radionuclides were measured in process offgas streams, it is likely that the Pb-210 and Po-210 are condensed in scrubber and condenser media and are transported to the liquid settling ponds. This assertion has been supported by measurements of high Po-210 concentrations in phossy water from the condensers and scrubbers [24].

Small but measurable quantities of U-238, Th-230, and Ra-226 (Th-230 assumed equivalent to U-238) are present in the ferrophosphorus. Approximately 1 to 2 percent of the input Po-210 is contained in the elemental phosphorus product.

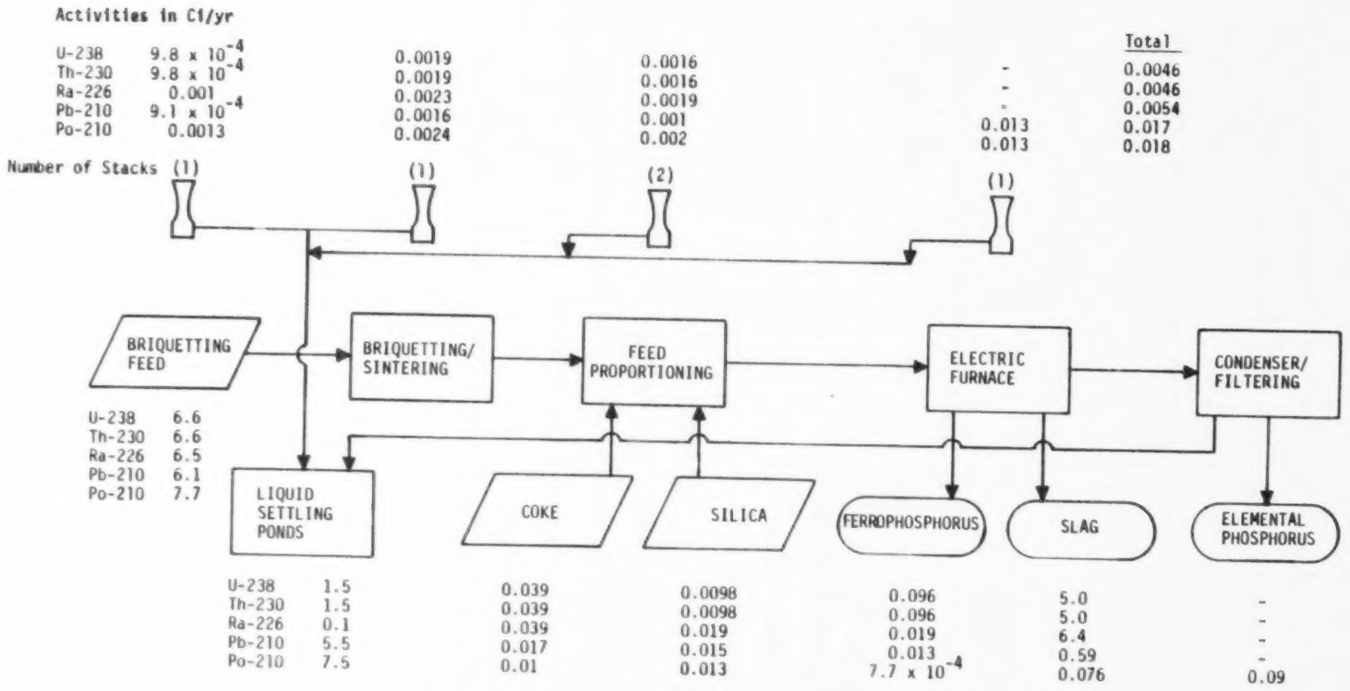
Activities in Ci/yr
U-238 9.8 x 10-4
Th-230 9.8 x 10-4
Ra-226 0.001
Pb-210 9.1 x 10-4
Po-210 0.0013
Number of Stacks (1)
0.0019
0.0019
0.0023
0.0016
0.0024
(1)
0.0016
0.0016
0.0019
0.001
0.002
(2)
-
-
-
0.013
0.013
(1)
Total
0.0046
0.0046
0.0054
0.017
0.018
BRIQUETTING FEED
U-238 6.6
Th-230 6.6
Ra-226 6.5
Pb-210 6.1
Po-210 7.7
BRIQUETTING/ SINTERING
FEED PROPORTIONING
ELECTRIC FURNACE
CONDENSER/ FILTERING
LIQUID SETTLING PONDS
U-238 1.5
Th-230 1.5
Ra-226 0.1
Pb-210 5.5
Po-210 7.5
COKE
0.039
0.039
0.039
0.017
0.01
SILICA
0.0098
0.0098
0.019
0.015
0.013
FERROPHOSPHORUS
0.096
0.096
0.019
0.013
7.7 x 10-4
SLAG
5.0
5.0
6.4
0.59
0.076
ELEMENTAL PHOSPHORUS
-
-
-
-
0.09

Figure 3-25. Activity Balance for the Mobil Chemical Plant.

3.3.8 Occidental Chemical Plant - Columbia, Tennessee

3.3.8.1 The Occidental Chemical Plant Site Characterization

The plant is located at 35° 39' 10" latitude and 87° 02' 04" longitude and at an elevation of 183 m on the northern edge of Columbia by the Duck River. It is adjacent to a chemical plant run by Union Carbide and lies 5 km east of the Monsanto elemental phosphorus plant. The plant is located in rolling hills and is accessed by railroad lines. Strip mines are scattered in the areas to the north and west of the plant. Numerous small creeks and ponds are scattered throughout the area. Figure 3-26 shows the locations of major features in the area.

Meteorology and Air Quality

The Occidental Chemical plant is located in Maury County and has the same meteorology and air quality conditions as the Stauffer-Tennessee plant (see Section 3.3.3.1).

Demography

See Section 3.3.3.1 for county population statistics. Actual population densities surrounding the plant are shown in Appendix A.

Land Use

See Section 3.3.3.1 for county land use.

3.3.8.2 The Occidental Chemical Process

Washed phosphate ore is shipped throughout the year to the plant by truck from local Tennessee strip mining operations. Only a small operating stockpile is maintained on site. The plant operates 24 hours per day, 365 days per year. A schematic of the plant operation is provided in Figure 3-27.

Washed phosphate ore is deposited in large piles near an overhead dragline that takes different grades of ore and mixes them to a predetermined composition (based on kiln operating requirements). The dragline moves the mixed ore up the stockpile slope and dumps it into an automated railcar. The railcar subsequently deposits the premixed feed ore onto a pan feeder that automatically feeds the ore onto an inclined conveyer, which in

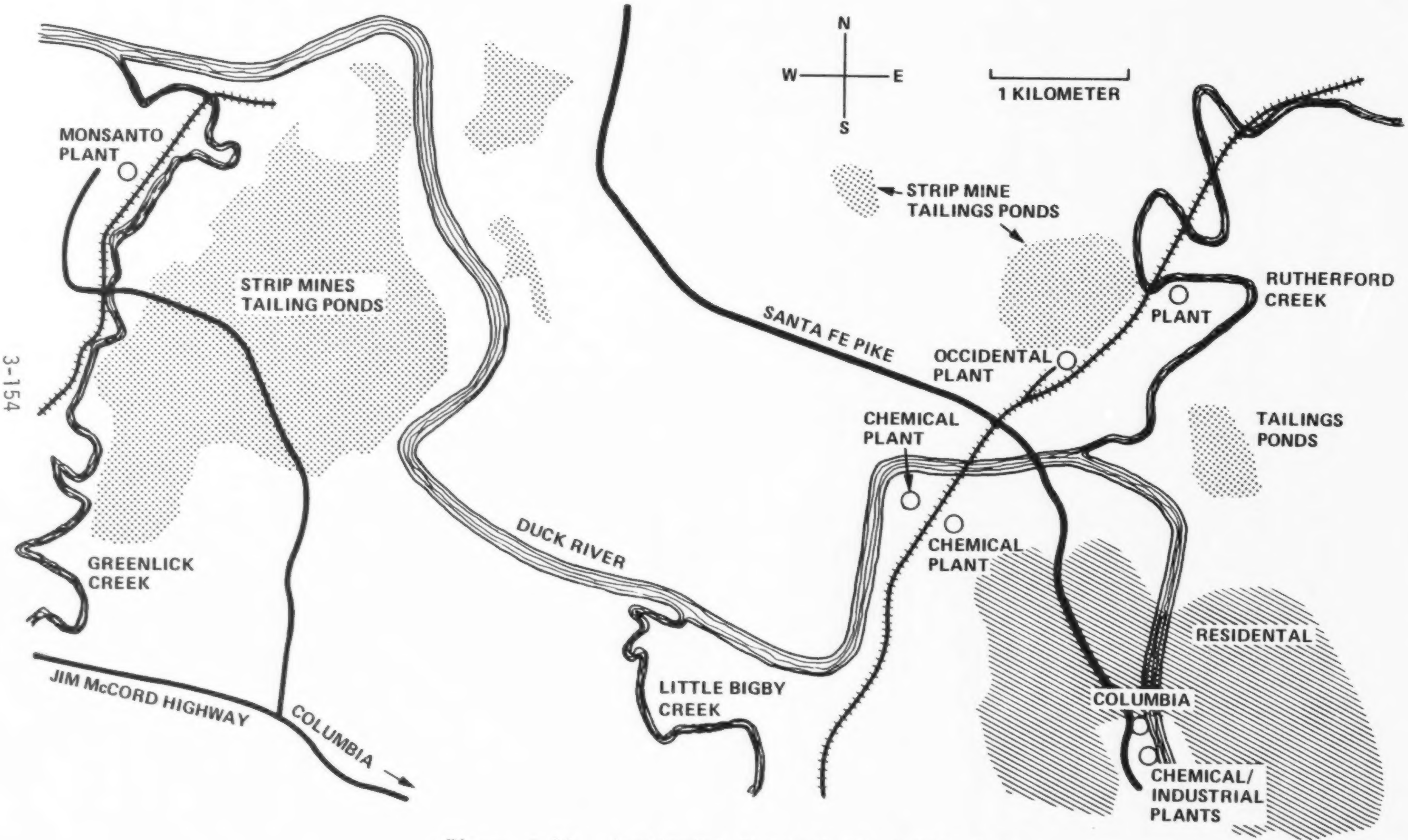
N
W
E
S
1 KILOMETER
MONSANTO PLANT
STRIP MINES TAILING PONDS
GREENLICK CREEK
JIM McCORD HIGHWAY
COLUMBIA
DUCK RIVER
LITTLE BIGBY CREEK
SANTA FE PIKE
STRIP MINE TAILINGS PONDS
OCCIDENTAL PLANT
CHEMICAL PLANT
CHEMICAL PLANT
PLANT
RUTHERFORD CREEK
TAILINGS PONDS
RESIDENTAL
COLUMBIA
CHEMICAL/ INDUSTRIAL PLANTS

Figure 3-26. Occidental Chemical Plant Site Area.

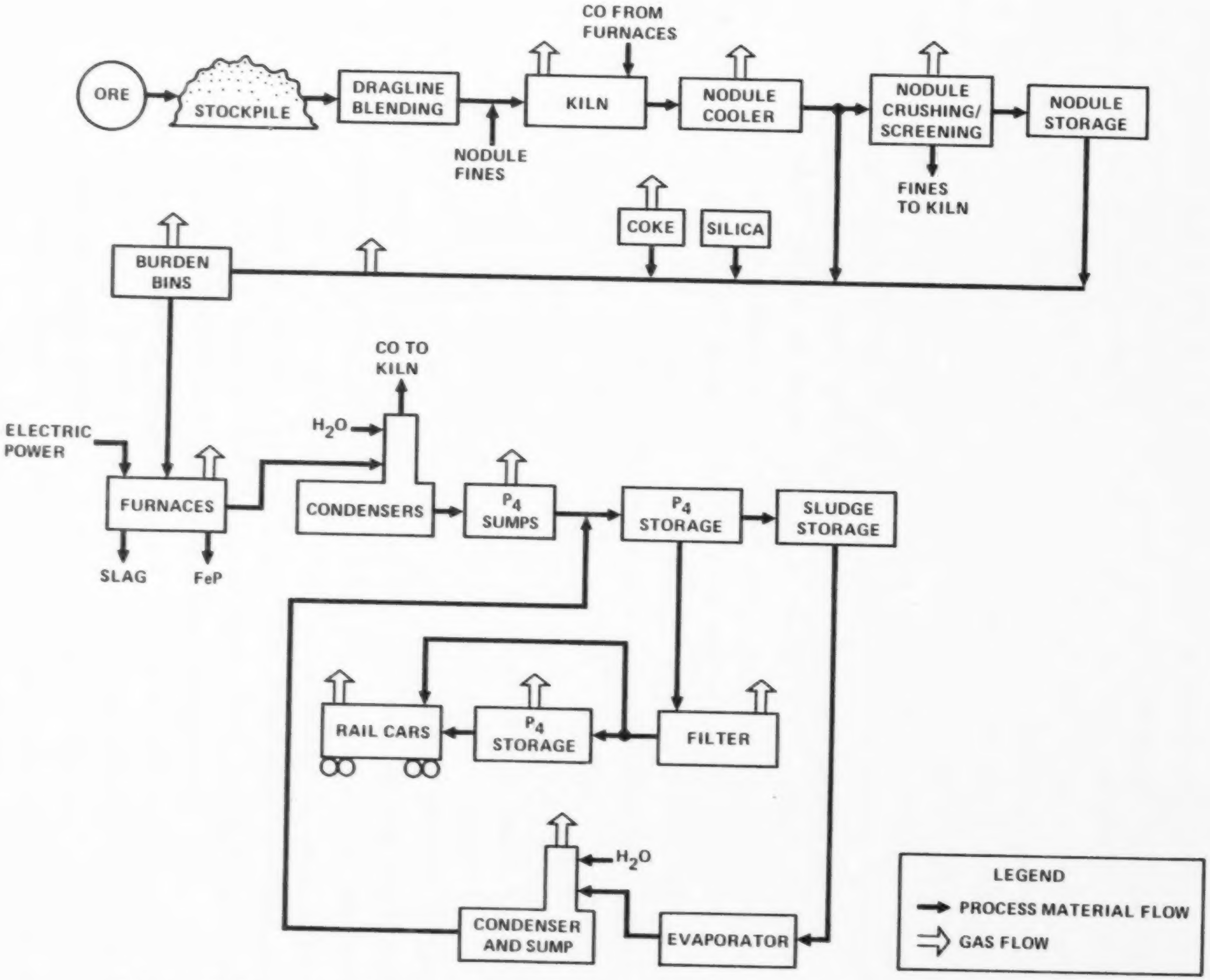
ORE
STOCKPILE
DRAGLINE BLENDING
NODULE FINES
KILN
CO FROM FURNACES
NODULE COOLER
NODULE CRUSHING/ SCREENING
FINES TO KILN
NODULE STORAGE
COKE
SILICA
BURDEN BINS
ELECTRIC POWER
FURNACES
SLAG
FeP
CO TO KILN
H_2O
CONDENSERS
P_4 SUMPS
P_4 STORAGE
SLUDGE STORAGE
RAIL CARS
P_4 STORAGE
FILTER
H_2O
CONDENSER AND SUMP
EVAPORATOR
LEGEND
PROCESS MATERIAL FLOW
GAS FLOW

Figure 3-27. Simplified Process Flow Diagram for the Occidental Chemical Plant.

turn, feeds the nodulizing kiln. The feed ore mixture is automatically and continuously weighed during transfer to the nodulizing kiln. Only the larger (#4) of two kilns (#1 and #4) has operated since 1981 and there are no current plans to operate the other kiln for the foreseeable future.

The nodulizing kiln causes the small phosphate particles to agglomerate into the larger masses needed for proper operation of the electric reduction furnaces. The rotary kiln heats the ore to its incipient melting point (about 1300°C), and the tumbling action causes the ore to agglomerate into the designed nodular form. The kiln is fueled with carbon monoxide generated in the electric reduction furnace operation. Supplemental coal or natural gas fuels may be used to heat the kiln as necessary. The kiln offgas is vented into a kiln-specific offgas treatment system of high-efficiency cyclones (eight operating in parallel) followed by low-energy venturi scrubbers (four operating in parallel) before being vented. The venturi scrubbers use a limed scrubbing liquor to remove fluorine, SO_2 and particulates. The dust and other materials removed from the offgas by the venturi scrubbers are pumped to a series of tanks for further treatment and are ultimately transferred to a series of settling lagoons. The lagoon water is purified and then recycled to the process or treated and discharged to the Duck River. The settled sludge is periodically dredged and landfilled. A major portion of the process water generated by the Occidental Chemical plant is evaporated by using waste process heat.

After leaving the kiln, the hot phosphate nodules pass through the nodule cooling and sizing operations. The nodules are screened and the oversized nodules are transferred to a crushing operation. The products from the initial screening step and crushing are then screened to remove fines, which are recycled to the kiln feed area. The properly sized nodular material is transferred to nodule storage and to the proportioning area. The dust from the first stage of the nodule cooling and sizing operations is collected by hood systems over the operating equipment and materials transfer conveyers. Gas is drawn through venturi scrubbers (four operating in parallel) followed by a separating tower before being vented. Emissions from the final screening operation are controlled by a Rotoclone. The slurry from the separator tower is sent to a settling tank from which water is recycled for use in the venturi scrubbers.

Silica and coke silos are located near the nodule storage hopper in the proportioning area. The coke storage hopper is vented and has a baghouse filter treatment system on the offgas to remove coke dust generated during material transfers to the hopper. The coke, silica, and nodules are analyzed frequently to determine the proportions needed for proper furnace operation. They are mixed using a proportioning weighing system that deposits the materials in layers on the furnace feed conveyer. The furnace feed conveyer transfers the material to the burden bins (i.e., furnace feed hoppers). Dust generated during the materials handling operations in the proportioning area is collected by hood systems and treated by a venturi scrubber and separator system.

In the burden area, the three burden bins (one per furnace) continuously gravity feed the electric reduction furnaces. Each burden bin is vented and dust generated during the materials handling is drawn through a Rotoclone for dust removal. Operating temperatures for the furnaces range from 1400 to 1800°C. The furnaces operate continuously and are periodically tapped to remove the molten slag and ferrophosphorus that accumulate at the bottom. Slag taps occur about every 30 minutes and ferrophosphorus taps occur about every 8 hours. The slag is poured into a water-sprayed cooling pit adjacent to the furnace building. The water causes the slag to cool and fracture after which it is loaded into trucks and either sold to a local company as an aggregate substitute or stockpiled on site. The ferrophosphorus is collected and stockpiled for further processing and sale to the automotive industry.

Offgases from the furnaces, composed mainly of carbon monoxide and phosphorus, are drawn through hot and cold condensers for phosphorus removal. The CO is then either routed to the rotary kiln and burned or flared to the atmosphere. The condensed phosphorus is collected in sumps and stored. Some phosphorus is sent to the on-site Occidental phosphoric acid plant. The remaining phosphorus is filtered and treated with carbon before being stored and ultimately shipped by railcar to various customers.

The slag tapping generates offgas fumes of P_2O_5 and dust. The taps occur in an enclosed building with hoods that collect the fumes. The fumes are drawn through a venturi scrubber and a cyclone separator before venting.

3.3.8.3 Occidental Chemical Feed Materials Characterization

The Occidental Chemical plant uses the same feed materials as the basic process plant described in Section 3.2. Table 3-41 provides the sources and typical values for composition, quantities utilized per short ton of phosphorus produced, and the radionuclide content of these feed materials. The range of values for the typical quantity reported is estimated as ±10 percent.

3.3.8.4 Occidental Chemical Product Materials Characterization

The Occidental Chemical plant produces the same basic products as described in Section 3.2. Table 3-42 provides the sales destination and typical values for the composition, quantities produced per ton of phosphorus produced, and the radionuclide content of these products. The range of values for the typical quantity is estimated as ±10 percent.

3.3.8.5 Occidental Chemical Plant Waste Materials

The Occidental Chemical plant has a minor quantity of waste materials. The phossy water and phosphorus sludge remain on site in appreciable quantities; however, the water is recycled. The settled sludge in the phossy water ponds is dredged and recycled.

Used furnace carbon is stored on site and is either recycled or sent to an on-site landfill. All phosphorus-contaminated metal and other scrap is sent to the on-site landfill. A significant stockpile of slag and a small stockpile of ferrophosphorus remain on site.

3.3.8.6 Occidental Chemical Process Airborne Emissions and Sources Characterization

A key objective of this study was to identify and characterize the major airborne emission points. To fulfill this objective, plant operating permits at the Tennessee Department of Public Health, Air Pollution Control Division, in Nashville, Tennessee, were obtained and a literature review was conducted. The Occidental Chemical plant was toured on October 14 and 15, 1982, and technical discussions were held with key plant staff. In addition, a literature review was completed.

Table 3-41. Occidental Chemical Phosphorus Plant Feed Materials Characterization.

Characteristic	Phosphate Ore	Coke	Silica
1. Source(1)	Tennessee strip-mining operation	Produced on site by Peabody Coal Company	Local Tennessee silica via river gravel
2. Chemical Composition, wt % (1)			
P_2O_5	26.5	-	-
SiO_2	16.0	3.3	96.0
CaO	36.5	-	0.25
Al_2O_3	3.5	1.3	1.5
Fe_2O_3	6.0	0.3	1.0
C	-	90.9 (dry basis)	-

Table 3-41. Occidental Chemical Phosphorus Plant Feed Materials Characterization. (Continued)

Characteristic	Phosphate Ore	Coke	Silica
3. Radionuclide content, pCi/g(2)			
U-238	2.7	0.4	0.3
Th-230	3.6	0.6	1.1
Ra-226	3.1	0.5	0.4
Pb-210	4.2	0.9	1.0
Po-210	4.1	0.8	0.8
4. Feed material utilization, ton/ton P_4 produced(3)	10.7	1.6	1.7
5. Electrical power, kWh/short ton P_4 produced(1)	13,500		

(1) Data presented to SAI staff at October 14 & 15, 1982, meeting at Occidental Chemical Corporation's Elemental Phosphorus Plant in Columbia, Tennessee.

(2) Assumed identical to materials at Monsanto-Tennessee plant.

(3) SAI engineering estimate.

Table 3-42. Occidental Chemical Phosphorus Plant Product Materials Characterization.

Characteristic	Phosphorus	Slag	Ferrophosphorus
1. Sales Destination(1)	- Various users - On-site Occidental phosphoric acid users	Southern Stone Company	Automotive industry
2. Utilization(1)	Varied	As aggregate	Paint additive
3. Chemical Composition, wt %(1)			
SiO_2	-	44.0	-
CaO	-	47.0	-
Al_2O_3	-	5.5	-
Fe_2O_3	-	-	-
P_2O_5	-	1.5	-
P	>99.9	-	23.0
Fe	10 ppm	-	70.0
Si	-	-	3.0
Ca	-	-	0.25

Table 3-42. Occidental Chemical Phosphorus Plant Product Materials Characterization. (Continued)

Characteristic	Phosphorus	Slag	Ferrophosphorus
4. Radionuclide content, pCi/g(2)			
U-238	-	2.4	1.1
Th-230	-	4.2	0.05
Ra-226	-	3.2	0.05
Pb-210	-	0.3	0.1
Po-210	-	0.4	0.05
5. Production, ton/ton P_4 produced(1)	1.0	8.0	0.5

(1) Data presented to SAI staff at October 14 & 15, 1982, meeting at Occidental Chemical Corporation's Elemental Phosphorus Plant in Columbia, Tennessee.

(2) Data calculated based on feed and information obtained from other area plants.

The process airborne emission points were divided into points sources, vents, and fugitive sources. This section reports only emission sources and characterizes emissions. The related air pollution control equipment is described in Chapter 4.

Point Sources

Table 3-43 lists the air pollution sources, emission points, and control equipment (characterized in Chapter 4). Point source emissions are generally continuous.

Vents

Table 3-44 lists the vents, including emergency vents, air pollution sources, emission points, and control equipment (characterized in Chapter 4). Vent emissions are intermittent.

Fugitive Sources

The fugitive emission sources are the slag pit and handling operations; miscellaneous furnace leaks (including furnace electrode seals); plant roads; and material stockpiles. Each of these areas is discussed below.

- Slag Pit and Handling

  The slag pit and handling operations are defined as fugitive emission sources. The molten slag tapped from the furnaces flows by gravity into a pit located adjacent to the furnace building. Water is sprayed onto the slag to cool and fracture it, after which it is further broken up and loaded into a truck. The slag is then hauled and either sold to a nearby aggregate plant or stored on site. This digging and loading operation raises a cloud of water vapor, dust, and P_2O_5 fumes.

- Miscellaneous Furnace Leaks

  Each furnace has three carbon electrodes that are continuously fed into the furnace. To prevent furnace gas from leaking around the electrodes, they are equipped with seals. However, periodic pressure surges caused by bridging and collapse of material in the

Table 3-43. Point Sources of Airborne Emissions for the Occidental Chemical Plant.

Air Pollution Source	Emission Points	Control Equipment
#4 rotary kiln system	#4 kiln offgas stack	Cyclones, venturi scrubbers (four), tower separators (two)
	Lime bin	Baghouse
Nodule cooling/sizing system	Nodule cooling/sizing stack	Hoods, covered conveyers, venturi scrubbers, tower separator and sump
	Crushers and pan conveyers	Rotoclone
Feed proportioning system	Coke fines hopper stack	Baghouse
Burdening system	Handling/transfer system stack	Hoods, covered conveyers
	Burden bin stacks (three)	Rotoclones (three), venturi scrubber
#1 furnace offgas system	#1 furnace condenser stack	Hot water spray condenser, cold water spray condenser
	#1 furnace evaporator and condenser sump	Venturi scrubber, cyclone separator
#2, 3 furnace offgas system	#2, 3 furnace condenser stack	Hot water spray condenser, cold water spray condenser
	#2, 3 furnace sumps	Venturi scrubber, cyclone separator
#1 furnace taphole fume system	#1 furnace taphole fume stack	Hoods, venturi, cyclone separator
#2 furnace taphole fume system	#2 furnace taphole fume stack	Hoods, venturi, cyclone separator
#3 furnace taphole fume system	#3 furnace taphole fume stack	Hoods, venturi, cyclone separator

Table 3-43. Point Sources of Airborne Emissions for the Occidental Chemical Plant. (Continued)

Air Pollution Source	Emission Points	Control Equipment
Ferrophosphorus processing system (inactive)	Ferrophosphorus ball mill stacks	Baghouses (two)
P_4 filtration system	Filter area	Venturi, cyclone separator
	Process heat/P_4 sludge processes stack	Venturi, cyclone separator
	Loading area	Venturi, cyclone separator
Lime storage system	Lime storage tank stack	Baghouse

Table 3-44. Vents and Emergency Vents for the Occidental Chemical Plant.

Air Pollution Source	Emission Points	Control Equipment
Rotary kiln CO flare	Kiln CO flare	-
Furnace CO flares	#1 furnace CO flare	-
	#2 furnace CO flare	-
	#3 furnace CO flare	-
Furnace pressure relief (PRV)	#1 furnace PRV	-
	#2 furnace PRV	-
	#3 furnace PRV	-

furnace breaks the seals and allows furnace gases to leak into the building.

- Plant Roads
  The plant roads are not all paved, and travel on these roads causes some fugitive dust emissions. These emissions are minimal, however, because a watering truck keeps the plant roads damp.

- Stockpiles
  The stockpiles of ore and nodules are not generally a problem because of the moisture content of the ore. But during dry conditions, dust from the stockpiles can be a problem. The nodule stockpile is in an enclosed building. The dry nodules are allowed, however, to free-fall as much as 6 m to the nodule pile, which results in some dust leaking from the enclosure.

Key Sources of Radionuclide Emissions

The estimated annual particulate radionuclide emissions from the Occidental Chemical plant are summarized in Table 3-45. In estimating these releases, the concentrations of Pb-210 and Po-210 in the particulate emissions from the kiln were assumed to be similar to those levels observed in the Monsanto-TN kiln emissions. This results in release rates of about 6000 pCi/s (0.19 Ci/yr) for Pb-210 and 7200 pCi/s (0.23 Ci/yr) for Po-210. The furnace tapholes are the other significant sources of volatilized radionuclide emissions, with combined annual releases of about 190 pCi/s (0.006 Ci/yr) of Pb-210 and much less Po-210. The principal sources of nonvolatile particulate emissions are the kiln, the nodule grate cooler, the crushing/screening stacks, and the CO flares.

Data are not available for Rn-222 releases from the Occidental Chemical plant. These releases are estimated at 1 Ci/yr using reported releases from other similar plants modified by the difference in quantities of Ra-226 processed annually.

Activity Balance

The flow of radioactivity through the Occidental Chemical plant is illustrated in Figure 3-28. As with other plants that use high temperature

Table 3-45. Stack and Emission Data for the Occidental Chemical Elemental Phosphorus Plant.

Source	Stack Geometry		Stack Gas Characteristics				Particulate Emissions		Radionuclide Emissions pCi/s (Ci/yr)				
	Height (m)	Diameter (m)	Flow (ACMM)	Exit Velocity (m/s)	Exit Temperature C° (K°)	Heat Release (cal/s)	(g/m^3)	(g/s)	U-238	Th-230	Ra-226	Pb-210	Po-210
#4 kiln(1)	30.5	4.7	4684	4.5	71 (344)	1.2×10^6	0.17	13.60	37	49	42	6000	7200
Lime storage bin	18.3	0.4	42	6.7	21 (294)	1.6×10^3	0.04	0.03	------- Negligible Radioactivity -------				
CO flare	16.8	0.3	126	29.6	43 (316)	1.4×10^5	0.50	1.05	7.9	7.5	8.1	7.6	3.5
Nodule grate cooler(2)	24.4	4.6	4077	4.1	25 (298)	2.4×10^5	0.02	1.54	11	11	12	11	5.1
Nodule screens/ crusher(2)	15.8	0.7	736	28.7	57 (330)	1.4×10^5	0.73	0.90	6.8	6.4	6.9	6.5	3.0
Coke silo(3)	9.1	0.4	294	39.0	27 (300)	1.9×10^4	0.27	0.13	0.05	0.08	0.07	0.1	0.1
Lime storage	15.8	2.7	4741	13.8	21 (294)	2.0×10^5	0.01	0.05	------- Negligible Radioactivity -------				
Belt to burden bins(2)	21.3	0.8	340	12.4	21 (294)	1.4×10^4	0.04	0.25	0.7	0.9	0.8	1.0	1.0
Burden bins(2)	8.2	0.5	237	20.1	51 (324)	1.1×10^4	0.05	0.21	0.6	0.8	0.7	0.9	0.9
#1 furnace taphole(4)	29.9	2.1	1274	6.1	32 (305)	1.2×10^5	0.02	0.34					
#2 furnace taphole(4)	29.9	2.1	1274	6.1	32 (305)	1.2×10^5	0.01	0.23	-	-	-	190	7.7
#3 furnace taphole(4)	29.9	2.1	1274	6.1	32 (305)	1.2×10^5	0.02	0.44					
FeP ball mill	6.2	0.4	106	17.7	35 (308)	1.1×10^4	0.02	0.03	------- Negligible Radioactivity -------				
FeP classifier	7.8	0.4	159	20.4	32 (306)	1.4×10^4	0.01	0.03					
#1 furnace CO offgas flare	33.5	0.9	267	7.0	45 (318)	2.8×10^5	0.22	0.98					
#2 furnace CO offgas flare	33.5	0.4	119	15.8	45 (318)	1.2×10^5	0.49	0.98	7.5	13	10	0.9	1.3
#3 furnace CO offgas flare	38.1	0.4	133	17.7	45 (318)	1.4×10^5	0.53	1.17					

Table 3-45. Stack and Emission Data for the Occidental Chemical Elemental Phosphorus Plant. (Continued)

Source	Stack Geometry		Stack Gas Characteristics				Particulate Emissions		Radionuclide Emissions pCi/s (Ci/yr)				
	Height (m)	Diameter (m)	Flow (ACMM)	Exit Velocity (m/s)	Exit Temperature C° (K°)	Heat Release (cal/s)	(g/m^3)	(g/s)	U-238	Th-230	Ra-226	Pb-210	Po-210
#2, 3 furnace condenser sump	15.2	0.3	65	14.9	50 (323)	1.1×10^4	0.05	0.05	------- Negligible Radioactivity -------				
P_4 sludge evaporators and condensers/sumps	15.2	0.6	187	11.0	45 (318)	2.8×10^4	0.13	0.39	0.9	1.6	1.2	0.1	0.2
P_4 sludge storage	10.2	0.5	82	6.9	27 (300)	4.5×10^3	~0	~0	------- Negligible Radioactivity -------				
P_4 tank cars	11.4	0.8	75	2.5	44 (317)	2.1×10^4	~0	~0	------- Negligible Radioactivity -------				
Totals									72 (0.0023)	90 (0.0028)	82 (0.0026)	6200 (0.20)	7200 (0.23)

(1) Assumes radionuclide concentrations in particulate emissions same as PO_4 ore for U-238, Th-230, and Ra-226; Pb-210 and Po-210 emissions based on Monsanto-TN emissions (factored by differences in quantities of ore processed and radionuclide concentrations).

(2) Assumes radionuclide concentrations in particulate emissions same as nodules [23].

(3) Assumes radionuclide concentrations in particulate emissions same as coke.

(4) Estimated from furnace stack effluent data of Monsanto-TN plant (factored by differences in quantities of ore processed and radionuclide concentrations).

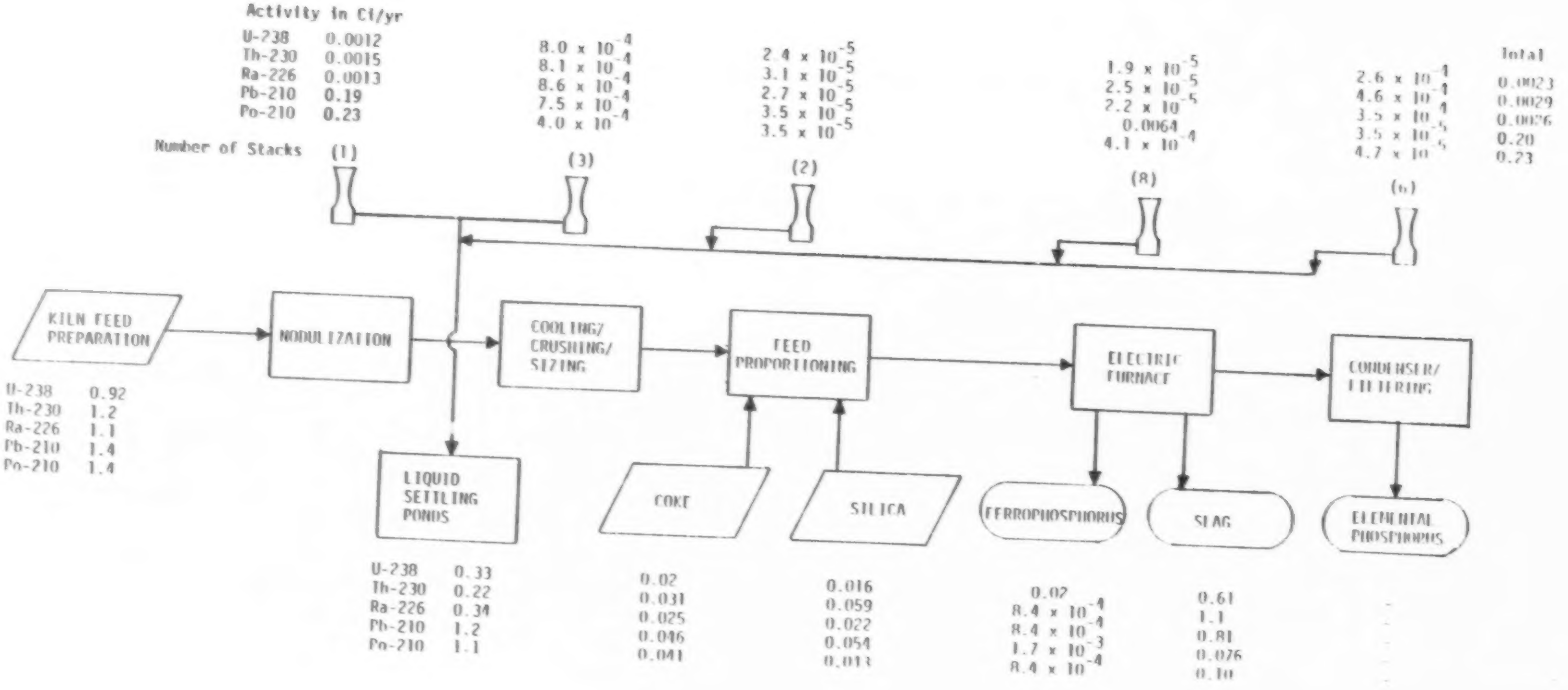
Activity in Ci/yr
U-238 0.0012
Th-230 0.0015
Ra-226 0.0013
Pb-210 0.19
Po-210 0.23
Number of Stacks (1)
8.0 x 10^-4
8.1 x 10^-4
8.6 x 10^-4
7.5 x 10^-4
4.0 x 10^-4
(3)
2.4 x 10^-5
3.1 x 10^-5
2.7 x 10^-5
3.5 x 10^-5
3.5 x 10^-5
(2)
1.9 x 10^-5
2.5 x 10^-5
2.2 x 10^-5
0.0064
4.1 x 10^-4
(8)
2.6 x 10^-4
4.6 x 10^-4
3.5 x 10^-4
3.5 x 10^-5
4.7 x 10^-5
(6)
Total
0.0023
0.0029
0.0026
0.20
0.23
KILN FEED PREPARATION
U-238 0.92
Th-230 1.2
Ra-226 1.1
Pb-210 1.4
Po-210 1.4
NODULIZATION
COOLING/ CRUSHING/ SIZING
FEED PROPORTIONING
ELECTRIC FURNACE
CONDENSER/ FILTERING
LIQUID SETTLING PONDS
U-238 0.33
Th-230 0.22
Ra-226 0.34
Pb-210 1.2
Po-210 1.1
COKE
0.02
0.031
0.025
0.046
0.041
SILICA
0.016
0.059
0.022
0.054
0.013
FERROPHOSPHORUS
0.02
8.4 x 10^-4
8.4 x 10^-4
1.7 x 10^-3
8.4 x 10^-4
SLAG
0.61
1.1
0.81
0.076
0.10
ELEMENTAL PHOSPHORUS

Figure 3-28. Activity Balance for the Occidental Chemical Plant.

kilns for ore nodulization, much of the Pb-210 and Po-210 contained in the ore is released in the kiln operation. This is evidenced by the depleted levels of these radionuclides in the output slag. In the Occidental Chemical process, about 65 percent of the input U-238, 85 percent of the Th-230, and 70 percent of the Ra-226 are accounted for in the slag. Approximately 75 percent of the Pb-210 and Po-210 are unaccounted for and are presumably transported by scrubber effluents to liquid settling ponds.

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4.0 EMISSION CONTROL TECHNIQUES

4.1 INTRODUCTION

The previous chapter generally described the U. S. elemental phosphorus industry, including airborne emission technologies in general use and airborne emissions for each major production process in each plant. This chapter discusses emission control techniques and equipment in more detail.

A general overview of emission control technology is given in Section 4.2, including emission types, equipment types, and costing methods. In Section 4.3, specific control equipment used in each plant is identified, design data and collection efficiencies reported, and capital, annual operating, and maintenance costs given. Section 4.4 discusses parameters that influence the effectiveness of these techniques and equipment in reducing emissions. Section 4.5 briefly discusses potentially applicable control processes, techniques, and equipment from other industries and their advantages and disadvantages.

4.2 EMISSION CONTROL TECHNOLOGY

4.2.1 Nonradioactive Emissions

Elemental phosphorus plant operators are primarily concerned with particulate emissions and the visible aspect of these emissions (opacity). Opacity refers to the degree to which emissions reduce the transmission of light and obscure the view of an object in the background. Opacity is determined by particulate concentrations and sizes. Generally, air pollution regulations state permissible opacity levels as a percentage, with 100 percent being totally opaque and 0 percent being transparent. Most regulations will allow up to 20 percent opacity for short periods but require essentially zero opacity during normal operations. Opacity can be judged visually, which is quite subjective. It can also be measured using a Ringelmann chart, which is an opacity scale with clear air at 0.

The quantity of particulates released may be determined by material balance, various types of emission factors, or source testing. The best method, source testing, typically uses a probe and a collection train maintained under vacuum to remove and collect particulates for analysis and weighing. Figure 4-1 shows the EPA particulate sampling train. Federal regulations require that EPA Method Five be used.

Estimates of emissions can be used to determine product loss, to estimate the performance of air pollution control equipment, and to determine if performance standards and emission regulations are being met. Existing standards affecting the elemental phosphorus industry include (depending on plant location) those for particulates and associated opacity, and those for fluorides. Emission control devices are installed in plants primarily to limit these releases and meet standards.

Plants generally comply with standards limiting mass emissions, but opacity limitations are not always met. Formation of only a small amount of P_2O_5 forms dense white fumes that can easily exceed opacity standards. A scrubber with a relatively high pressure drop is sometimes needed to ensure compliance with opacity standards.

4.2.2 Radioactive Emissions

Currently, no airborne emission control technologies are used by the plants to specifically limit the release of radioactivity but the control technologies used for particulates and fluorides are also effective in reducing emissions of radioactive particulate materials. There are, however, no techniques or emission control systems used to control volatile Pb-210 and Po-210 emissions. Data on the capability of existing technologies to control these volatile emissions are not available.

This chapter mainly discusses the control systems installed to remove particulates and fluorides and their efficiencies, which should also indicate their efficiencies in removing radioactive particulates. The two major sources of radioactive emissions are calciner operations and furnace tapping operations. The calciner offgas is a major source of radioactive particulates and volatile Pb-210 and Po-210; it is also the major source of fluorides.

Calciners are usually vented under induced draft to equipment controlling dust, fluorides and SO_2. Typically, calciner offgas moves

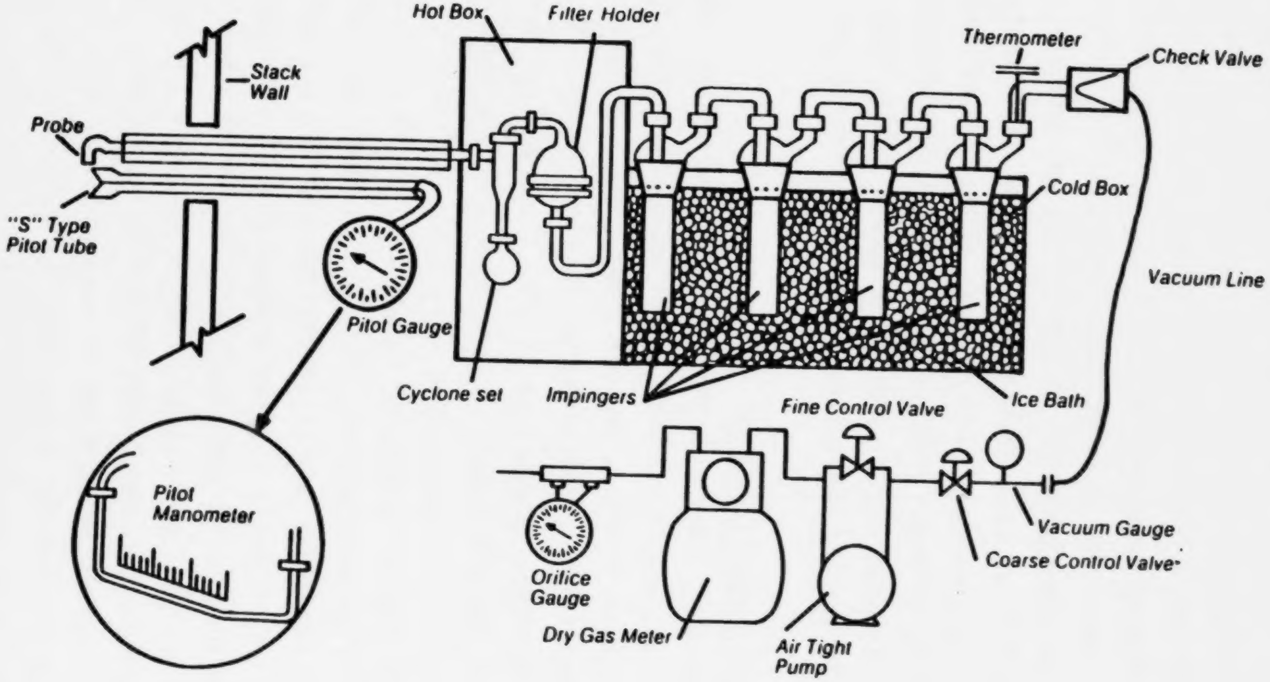

Hot Box
Filter Holder
Thermometer
Check Valve
Stack Wall
Probe
"S" Type Pitot Tube
Cold Box
Vacuum Line
Pitot Gauge
Cyclone set
Impingers
Fine Control Valve
Ice Bath
Pitot Manometer
Orifice Gauge
Vacuum Gauge
Coarse Control Valve
Dry Gas Meter
Air Tight Pump

Figure 4-1. Environmental Protection Agency Sampling Train.

through a dry dust collector, which removes most of the particulates, and then through a water spray tower scrubbing process. Total particulate removal efficiencies range from approximately 97 to 99 percent.

Furnace taphole fumes are corrosive, hygroscopic, and sticky. Particulate and fluorine concentrations vary widely, depending upon the amount of furnace gas allowed to escape through the taphole. Tapping operations are also a major source of P_2O_5. A typical particle size analysis of fume particles shows the average particle diameter to be 0.6 μm, with 7 weight percent of the particles <0.2 μm; 78 weight percent <1.0 μm; and 96 weight percent <2.0 μm [1]. Methods to control taphole fumes vary with plants, but the method most used is some variation of a high-energy wet venturi scrubbing system. Particulate removal efficiencies of existing equipment range from 80 to 95 percent. Although little data are available, P_2O_5 removal efficiencies for existing equipment are >95 percent.

4.2.3 General Types of Control Equipment

The general types of airborne control equipment used in elemental phosphorus plants were introduced and briefly discussed in Section 3.2.5. This section expands on these general types, which include mechanical collectors, electrostatic precipitators, fabric filters, and wet scrubbing devices. How each type operates is briefly discussed and the basic features are described. Table 4-1 summarizes the basic features of each type of device. Specific equipment associated with each plant is discussed in Section 4.3, and detailed technical information is given in Appendix B.

In all these collectors, dirty gas is moved through a gas cleaning device by a fan and clean gas is discharged through a stack to the atmosphere. The fan is usually located downstream of the cleaning device to protect it from the erosive and possible corrosive or unbalancing effects of the entrained particulate matter. Collector size and cost are usually directly proportional to the volume of gas to be cleaned. Collection efficiency is expressed in percent and is determined by subtracting the weight of the particles leaving the device from the weight of the particles entering the device and dividing by the weight of the particles entering the device times 100.

Generally, devices are classified as either primary or secondary collectors. Mechanical collectors have generally low collection efficien-

Table 4-1. Fundamental Operating Characteristics of Commercial Particulate Collectors(1).

Basic Type	Basic Operating Force	Specific Type	Basic Measure and Unit of Capacity	Typical Capacity in CFM of Gas Per Basic Measure of Capacity	Typical Required Plan Area for Collector to Clean 100,000 CFM(2) (ft^2)	Typical Pressure Required and % Collection Efficiency On Fine Dust(3)		Effect on Efficiency of Operation at Over or Under Capacity(4)	
						(in W.G.)	(%)	(Over)	(Under)
Mechanical collectors	Gravity	Settling chamber	Casing volume (cu ft)	20	2600	0.2	25	Down	Up
	Inertia	Baffle	Inlet area (sq ft)	1200-2600	300	0.5	40	Up	Down
	Centrifugal	High-efficiency cyclones	Inlet area (sq ft)	3000-3600	125	4	80	Up	Down
Fabric filters	Filter cake filtration	Manual cleaning	Fabric area (sq ft)	1-4(5)	1000	4	99	Down	No change
	Filter cake filtration	Automatic shaker cleaning	Fabric area (sq ft)	1-4(5)	1000	5	99	Down	No change
	Filter cake filtration	Automatic reverse jet cleaning	Fabric area (sq ft)	3-8(5)	600	8	99	No change	No change
Electrostatic precipitators	Electric	Single field	Collectrode area (sq ft)	5	270	0.5	99	Down	Up
	Electric	Multiple field	Collectrode area (sq ft)	3	500	0.5	95	Down	Up
Wet scrubbers	Liquid capture	Improvement baffle	Baffle cross-sectional area (sq ft)	500-600	300	4	80	Up	Down
	Liquid capture	Packed tower	Bed cross-sectional area (sq ft)	500-700	250	7	90	Down	Up
	Liquid capture	Venturi	Throat area (sq ft)	7000-30,000	100	30	99	Up	Down

(1) Data from Ref. [2].
(2) Plan areas do not include connecting flues.
(3) Fine dust is considered to be 70 weight percent <10 µm.
(4) Some collectors can be modified to maintain collection efficiency at over or under capacity.
(5) Air-to-cloth ratio.

cies and are the main primary collectors. The secondary collectors may be electrostatic precipitators, fabric filters, or wet scrubbers. These are the principal collectors capable of meeting existing atmospheric standards.

4.2.3.1 Mechanical Collectors

There are many different designs of mechanical dust collectors, each with a slight advantage or disadvantage when compared with the others. The basic types of mechanical dust collectors are the gravity settling chamber, the inertia baffle separator, and the high-efficiency centrifugal unit. Selection for a given application depends on collection efficiency required, quantity and characteristics of the contaminant, and conditions of the gas stream. In addition, fire safety and explosion control are always considered.

Gravity settling chambers, as shown in Figure 4-2, use the weight of the particulates to separate them at low velocities from the gas. Velocities are typically 0.3 to 3 m/s (1 to 10 ft/s). The units are large and collection efficiency is low, but the initial cost is generally quite low. Efficiency increases as the volumetric load decreases because the lower the velocity, the better the separation. Efficiency can be improved by adding baffles (which tend to impart a sudden high-velocity turn to the dust-laden gas) on the inlet and the outlet of the gas stream. Baffled settling chambers are used at the FMC elemental phosphorus plant for control of offgases from the calciner coolers.

The third basic type of mechanical dust collector is a centrifugal collector, commonly called a cyclone. The cyclone is a very simple and reliable device with a high efficiency compared with the other types of mechanical collectors and is widely used in elemental phosphorus plants. This collector uses the velocity of an inlet stream to throw the heavier particles to the outside of the collector, creating both a descending outer vortex and an ascending inner vortex. The descending vortex holds the heavier particulates against the outside walls through centrifugal force. The particles descend into a hopper at the bottom. The ascending vortex of cleaned gas rises through the center of the cyclone and through a baffle to the clean gas outlet. Cyclones are usually smaller than gravity or baffle-type separators, but they can handle a greater flow. Most cyclones operate at an inlet velocity of 15 to 20 m/s (50 to 67 ft/s), and the energy

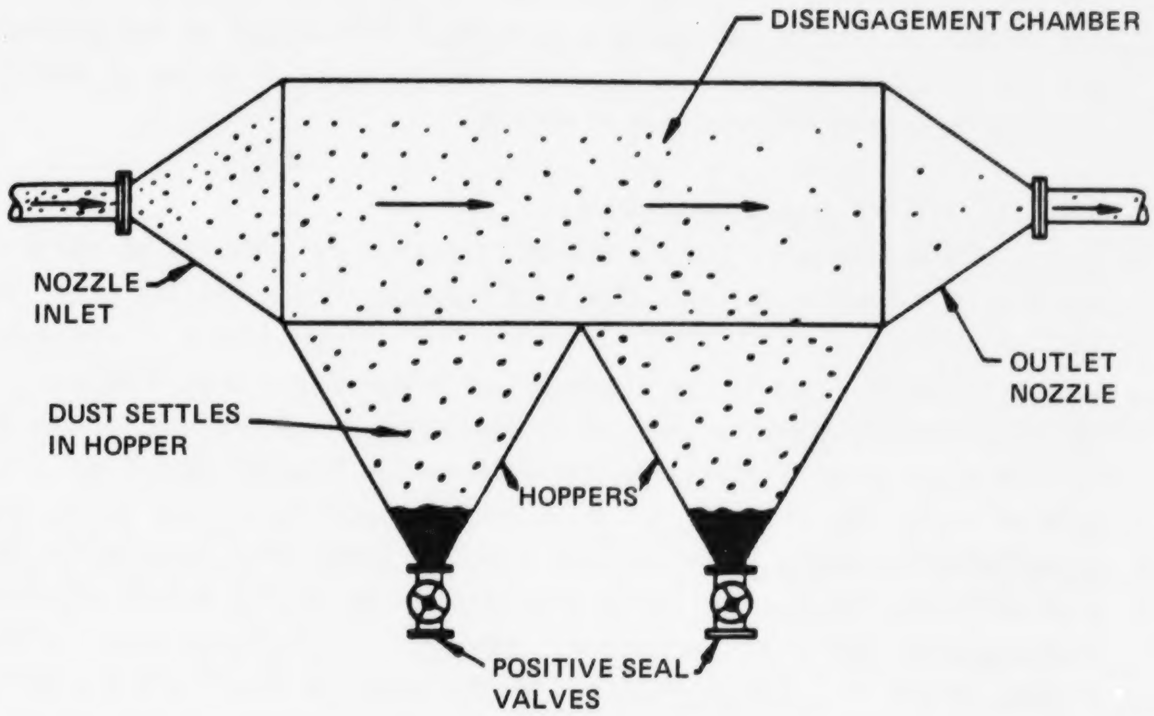

DISENGAGEMENT CHAMBER
NOZZLE INLET
OUTLET NOZZLE
DUST SETTLES IN HOPPER
HOPPERS
POSITIVE SEAL VALVES

Figure 4-2. Gravity Settling Chamber.

requirement is proportional to the square of the inlet velocity. When handling atmospheric air, the draft loss generally ranges from 10 to 23 cm (4 to 9 in) W. G. when measured as a difference of static pressure between the inlet and outlet. A typical single cyclone type collector is shown in Figure 4-3.

Cyclones are generally low cost and because of the relatively simple operation require little maintenance. They generally have low efficiencies, especially with fine dust (usually below 90 weight percent) and are subject to erosion and possible corrosion. Efficiences of dry cyclones are low enough that another particulate removal device in series is usually required to comply with existing standards.

4.2.3.2 Electrostatic Precipitators

Electrostatic precipitation is a physical process by which a particulate suspended in a gas stream is electrically charged and under the influence of the electric field, separated from the gas stream (Figure 4-4). In precipitators used in the elemental phosphorus industry, a negative-charged corona is normally produced by applying a rectified high voltage to rows of wires or metal strips suspended vertically in a horizontal gas flow (Figure 4-5). An electric field is established between the wires and grounded metal plates, which are also suspended vertically, parallel to the rows of wires and parallel to the direction of gas flow. In the electric field between the wires and plates, the charged particles move to the plates, where they are deposited. As the layer of deposited particles builds up on the collection electrodes, it is periodically knocked off by a rapper or vibrator on the electrodes, and the particulate material falls into a hopper for removal. While precipitator size is usually dictated by the gas flow through it, at least in terms of cross-section, unit depth depends primarily upon the resistivity of the dust to be collected. Electrostatic precipitators (ESPs) have relatively low power requirements compared with other collectors, have low pressure drops, have high collection efficiences for submicron particulates, and are not particularly sensitive to the exhaust stream temperature. However, electrostatic precipitators are very large, are initially costly, are unsuitable for flammable or explosive materials, and do not remove gaseous contaminants. The pressure drop across an electrostatic precipitator is usually less than 2.5 cm (1 in) W. G.

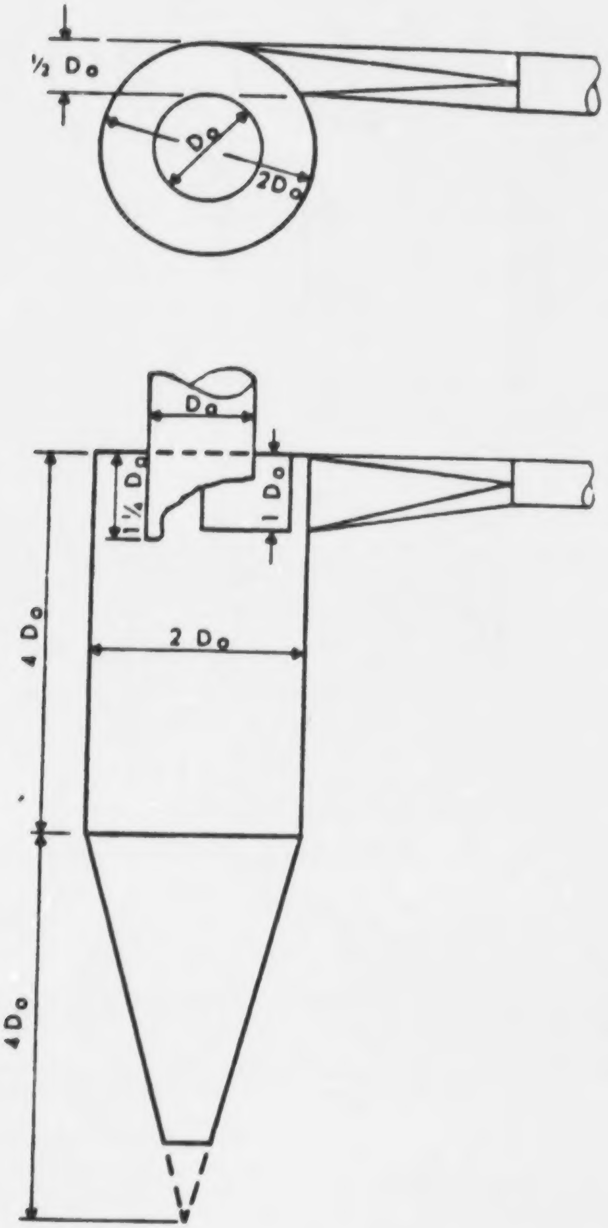
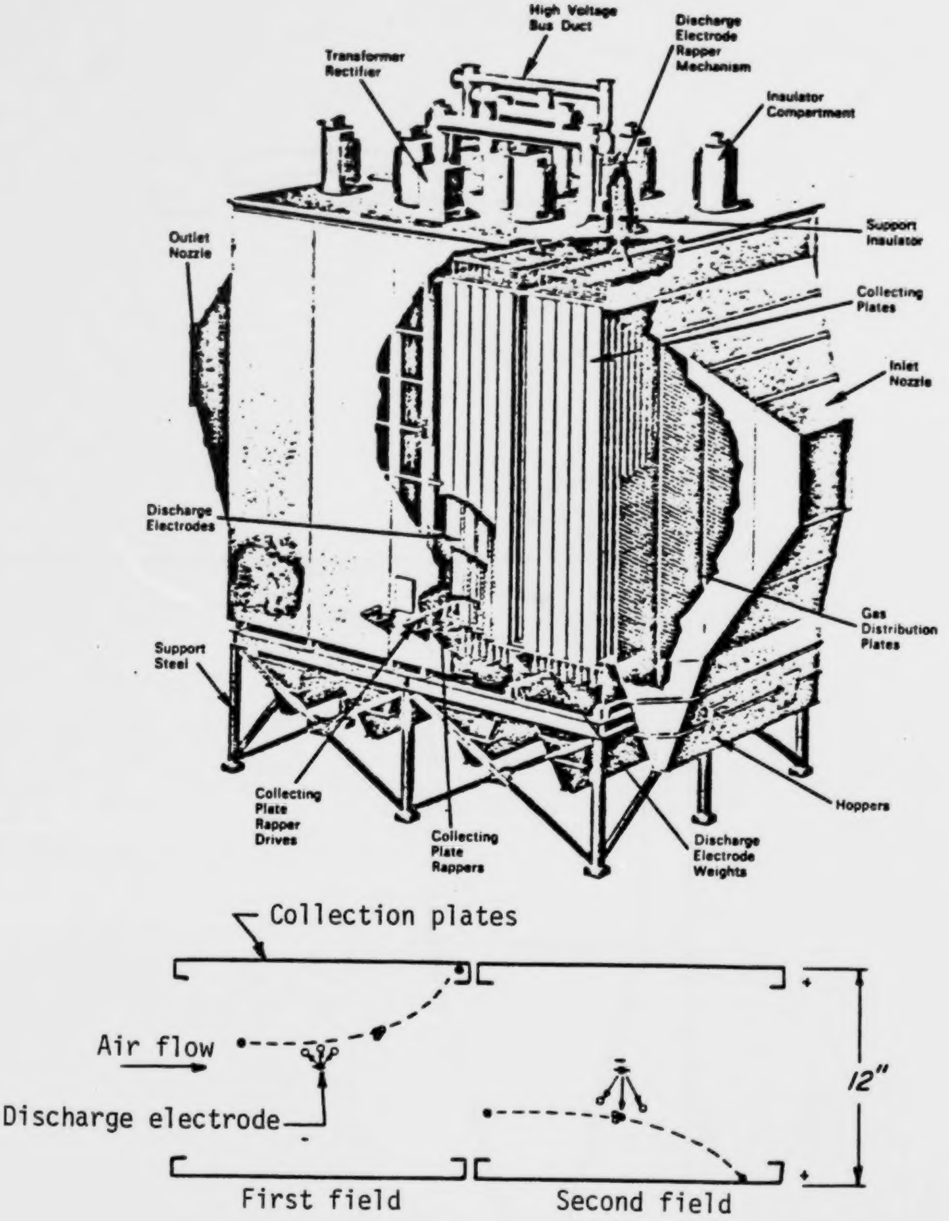

½ Do
Do
2Do
Do
1¼ Do
1 Do
4 Do
2 Do
4 Do

Figure 4-3. Typical Cyclone.


High Voltage Bus Duct
Discharge Electrode Rapper Mechanism
Transformer Rectifier
Insulator Compartment
Support Insulator
Outlet Nozzle
Collecting Plates
Inlet Nozzle
Discharge Electrodes
Gas Distribution Plates
Support Steel
Hoppers
Collecting Plate Rapper Drives
Collecting Plate Rappers
Discharge Electrode Weights
Collection plates
Air flow
Discharge electrode
12"
First field
Second field

<ins>To collect difficult dusts</ins>
Change treatment time
1. Lengthen passage
2. Lower velocities
3. Closer plate spacing

Figure 4-4. Typical High Voltage Electrostatic Precipitator [3].

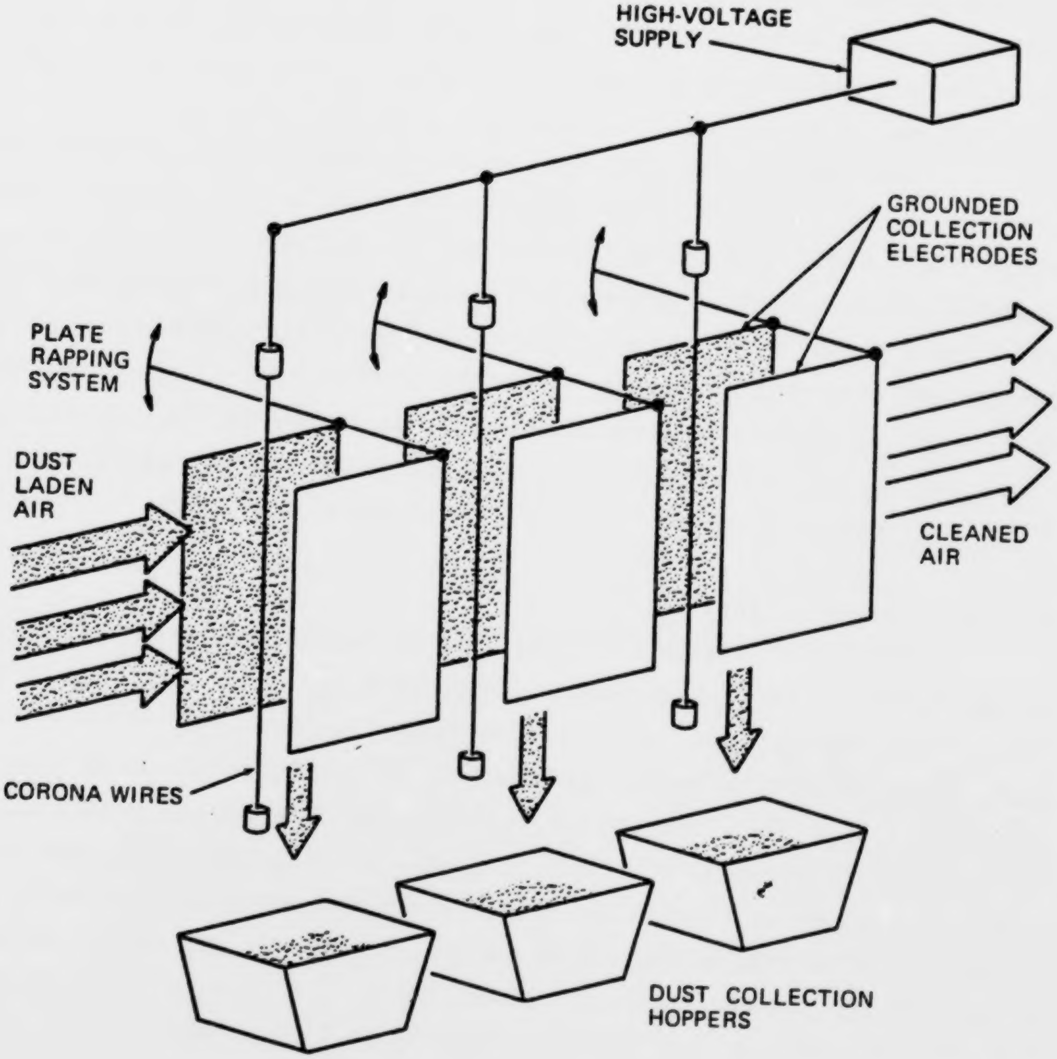

HIGH-VOLTAGE SUPPLY
GROUNDED COLLECTION ELECTRODES
PLATE RAPPING SYSTEM
DUST LADEN AIR
CLEANED AIR
CORONA WIRES
DUST COLLECTION HOPPERS

Figure 4-5. Schematic Diagram of an Electrostatic Precipitator Collecting Dust [4].

Dry electrostatic precipitators are used by several plants, primarily for primary dust removal from furnace offgases. In the past, dry ESPs have been used for furnace taphole fume particulate control but with limited success. Currently, no plants use them this way. There is a general consensus within the elemental phosphorus industry that dry electrostatic precipitators may present a significant safety hazard and other operational difficulties, such as frequent plugging.

The Stauffer Chemical-Montana plant uses wet electrostatic precipitators on its calciner offgas and furnace taphole fume control systems. These Fluid Ionic Hydro-Precipitrol wet electrostatic precipitators use a concentric arrangement of cylindrical elements with gas entering the bottom and flowing upward through a thin film of liquid flowing downward from a pressurized distributing system. These units offer several operating advantages over dry electrostatic precipitators, including the ability to simultaneously collect particulates, aerosols, condensables, and gases (SO_2, fluorides, etc.). Pressure drop is 5 cm (2 in) W. G. or less.

4.2.3.3 Fabric Filters

Perhaps the most efficient type of particulate removal equipment is the fabric filter, which uses a porous mass to filter out fine particulates from a gas stream. A variety of woven and nonwoven fabrics can be used. These collectors remove particulates by interception, impaction, and diffusion. They are often called baghouses because they typically consist of a number of vertical, tubular filter bags or flat bags. The dust either enters the chamber in which the filter elements are suspended and is collected on the outside of the bag or enters the tubular bag and is collected on the inside. In both types of system, there is a means of intermittently removing the dust from the bags and dropping it into a hopper at the bottom of the baghouse.

Fabric collectors are not 100 percent efficient but efficiencies of well-designed, adequately sized, and properly operated fabric collectors exceed 99 percent, often as high as 99.9+ percent on a weight basis. A given fabric is selected for its mechanical, chemical, or thermal characteristics. Fabric collectors are sized to provide sufficient filter area to allow operation without excessive pressure drop. The filter area required depends on many factors, including:

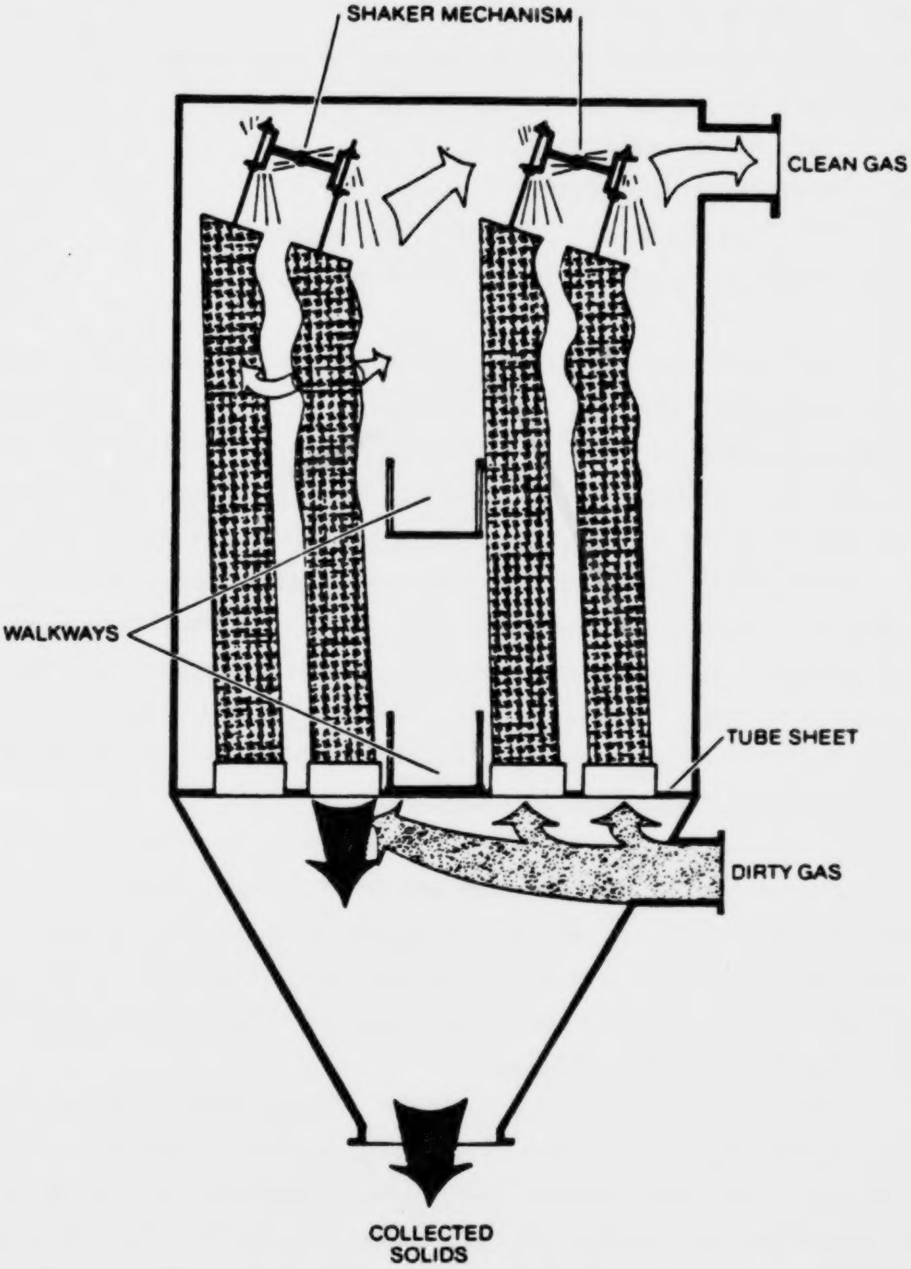
- Release characteristics of the dust
- Porosity of the dust cake
- Concentration of dust in the carrier gas stream
- Type of fabric and surface finish, if any
- Type of reconditioning
- Reconditioning interval
- Air flow patterns within the collector
- Temperature and humidity of the gas stream

The major reconditioning (cleaning) methods used by fabric collectors are mechanical shaking, reverse flow (low pressure), and reverse pulse jet (high pressure). All are found among existing elemental phosphorus plants, but the reverse flow and reverse pulse jet types are most prevalent. Figures 4-6, 4-7, and 4-8 show the schematic arrangements of these systems.

The mechanical shaker type baghouse (Figure 4-6) has the bag supported by a structural framework that is free to oscillate when driven by a small electric motor. Periodically, a damper isolates a compartment of the shaker baghouse from gas flow. The bags in the compartment are then shaken for approximately one minute during which the collected dust drops from the bag into the hopper for subsequent removal.

The reverse flow baghouse (Figure 4-7) is equipped with an auxiliary fan that forces air through the bags in the direction opposite to filtration. This backwash action collapses or expands the bag fracturing the dust cake, which is then dislodged into a hopper when the bag is reinflated. If the unit operates under suction, then the main fan is located on the clean side of the baghouse.

The reverse pulse jet baghouse (Figure 4-8) incorporates a small venturi at the top or open end of the bag, which is fed by a jet of high-pressure air. The most common designs use compressed air at 80 to 100 psig while others use an integral pressure blower. The air line to each venturi is controlled by a solenoid valve actuated by a timer. To clean a specific bag or section of bags, a high-pressure air jet pulls in additional air, which expands the bag and breaks the dust cake from the outside of the bag. Because reverse pulse jet systems normally clean no more than 10 percent of the fabric at a time and because the induced secondary flow blocks normal



SHAKER MECHANISM
CLEAN GAS
WALKWAYS
TUBE SHEET
DIRTY GAS
COLLECTED SOLIDS

Figure 4-6. Mechanical Shaker Baghouse.

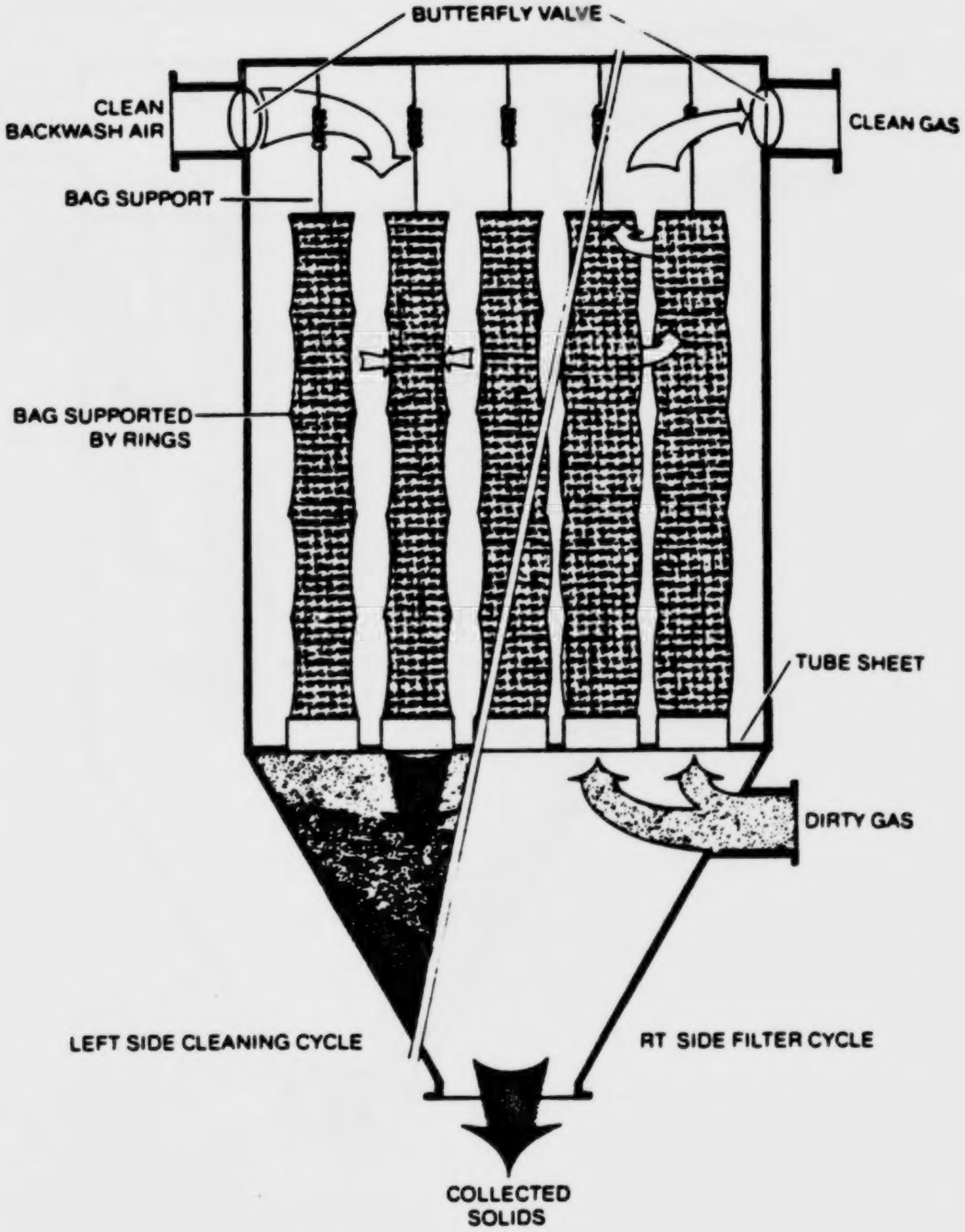

BUTTERFLY VALVE
CLEAN BACKWASH AIR
CLEAN GAS
BAG SUPPORT
BAG SUPPORTED BY RINGS
TUBE SHEET
DIRTY GAS
LEFT SIDE CLEANING CYCLE
RT SIDE FILTER CYCLE
COLLECTED SOLIDS

Figure 4-7. Reverse Flow Baghouse.

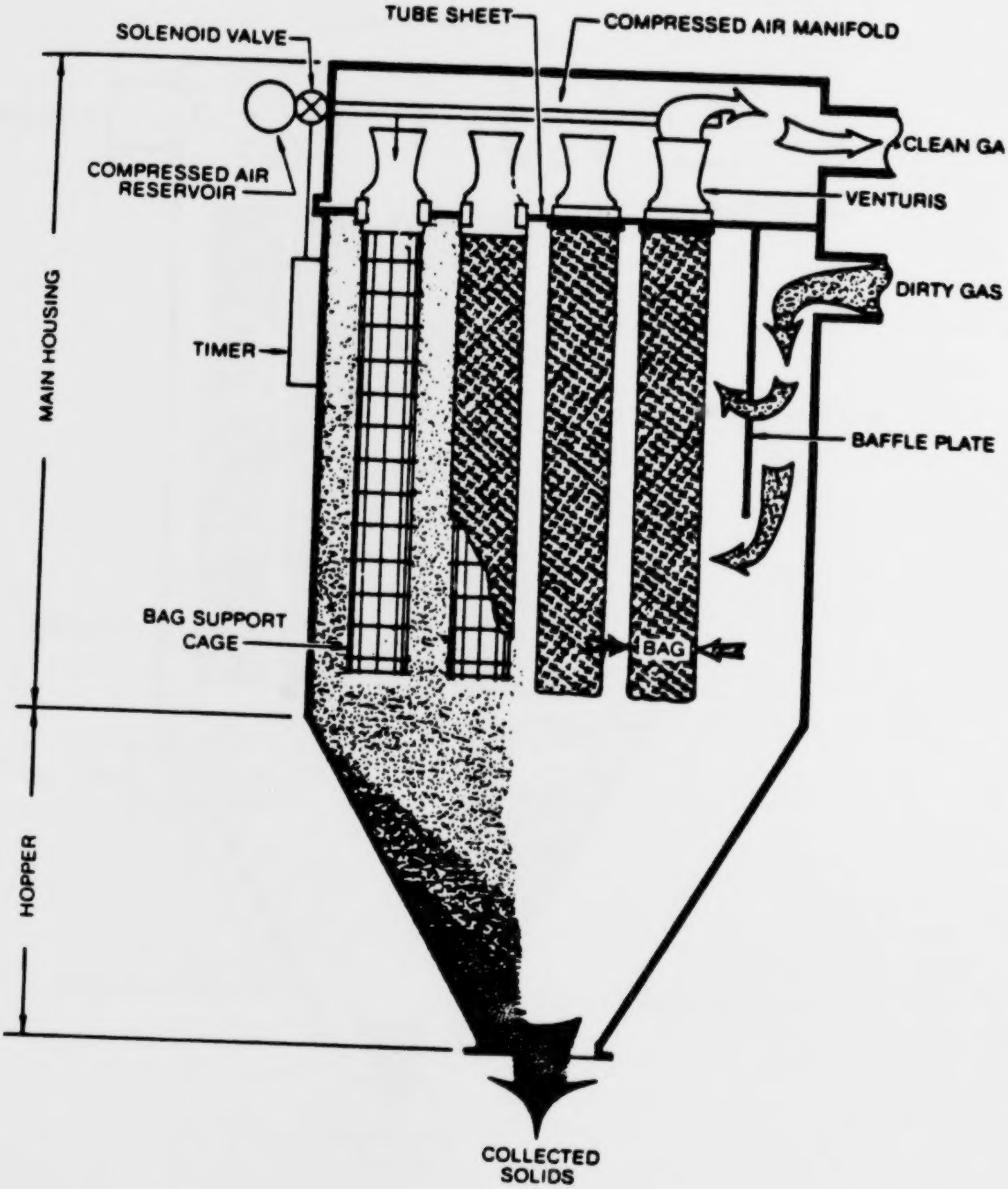

TUBE SHEET
COMPRESSED AIR MANIFOLD
SOLENOID VALVE
CLEAN GA
COMPRESSED AIR RESERVOIR
VENTURIS
MAIN HOUSING
DIRTY GAS
TIMER
BAFFLE PLATE
BAG SUPPORT CAGE
BAG
HOPPER
COLLECTED SOLIDS

Figure 4-8. Pulse Jet Baghouse.

flow or filtration during cleaning, reconditioning can take place while the collector is in service without compartmentation and dampers. The cleaning intervals are adjustable and much more frequent than the intervals used by shaker type systems.

The sizing or rating of a fabric filter is expressed in terms of air volume rate versus filter media area. The resultant ratio is called the air-to-cloth ratio with units normally expressed in CFM per square foot of cloth. The air-to-cloth ratio usually depends on the specific application and is generally determined empirically for a specific type of dust. Since the reverse pulse jet system usually operates at high air-to-cloth ratios, it is smaller and tends to be less expensive. However, use of compressed air is expensive and the operating costs of the reverse pulse jet are usually higher than for the reverse flow system. Table 4-2 provides a comparison of the various characteristics of fabric collectors.

For large applications, the filter baghouse is a good emission control method as long as the temperature is not too high. The baghouse operates on a dry basis, is efficient on submicron particulates, and operates on a very low pressure drop resulting in low power requirements. However, the baghouse may clog in gas streams near the dewpoint and cannot be considered for use at temperatures above approximately 315°C (600°F) and probably not at somewhat lower temperatures. It requires a relatively large space and is expensive to maintain. For large installations, the initial cost of the baghouse and the electrostatic precipitator are about the same, with the baghouse often being slightly less expensive but having a higher pressure drop.

4.2.3.4 Wet Scrubbers

There are literally hundreds of commercially available designs of wet scrubbers for removing particulates from gas streams. In the elemental phosphorus industry, plants usually use commercially available scrubbing equipment, but some plants custom fabricate equipment according to in-house design. Wet scrubbers can handle high temperature and moisture-laden gases and eliminate the secondary dust problem associated with disposal of collected material. Water, however, may introduce corrosion and may require freeze protection in cold climates. Space requirements are usually nominal, and pressure losses vary widely with design. The size and initial cost

Table 4-2. Summary of Fabric Type Collectors and Their Characteristics [3].

Characteristic	Interruptible Operation Light to Moderate Loading	Interruptable Operation Heavy Loading		Continuous Operation Any Loading	
Fabric reconditioning requirement	Intermittent	Continuous		Continuous	
Type of reconditioning	Shaker	Shaker	Reverse air (low pressure)	Reverse pulse- (high pressure) pulse jet or fan pulse	
Collector configuration	Single compartment	Multiple compartments with inlet or outlet dampers for each		Single Compartment	
Fabric configuration	Tube or envelope	Tube or envelope	Tube	Tube or envelope	Pleated cartridge
Type fabric	Woven	Woven		Non-woven (felt)	Non-woven (paper mat)
Air flow	Highly variable	Slightly variable		Virtually constant	Virtually constant
Normal rating (filtration velocity, fpm)	1 to 6 fpm	1 to 3 fpm	1 to 2 fpm	5 to 12 fpm	<1 to 2.5 fpm

generally are much lower than that for a baghouse or electrostatic precipitator, but the operating cost is generally much higher because of the higher pressure drop.

Wet collectors have a wide range of collection efficiency. For well-designed equipment, it is generally accepted that efficiency depends only on the energy input per volumetric gas flow rate and is independent of operating principle. Wet collectors have an inherent ability to humidify. Humidification, the process of adding water vapor to the gas stream through evaporation, may be either advantageous or disadvantageous depending on the situation. For a hot, unsaturated stream, evaporation reduces the temperature and the volume of the gas stream leaving the collector. Thus, a fan operating behind or on the clean air side of the collector may be smaller and will definitely require less power than if there had been no cooling through the collector.

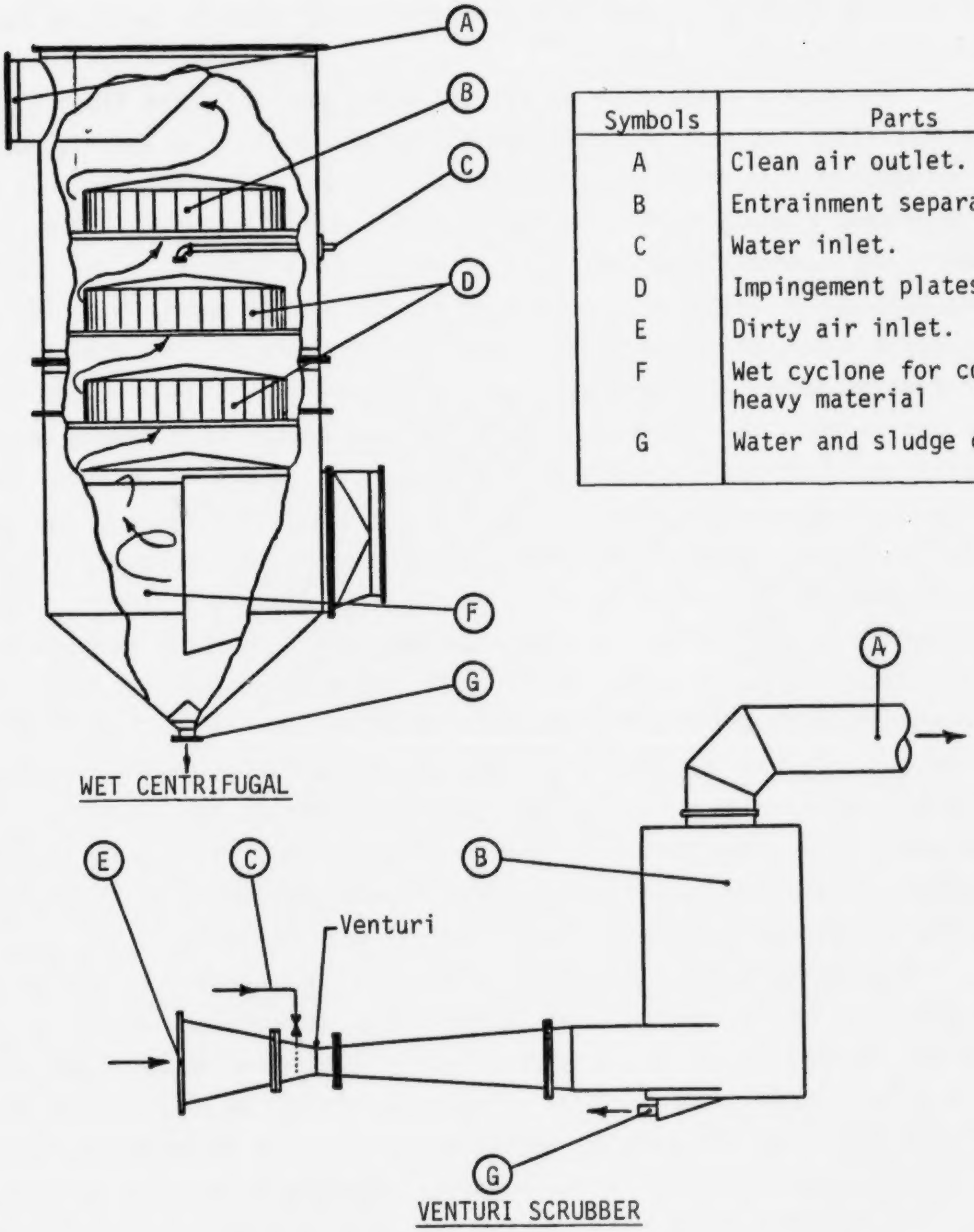
Of the wet scrubbers available, only the venturi can usually be considered suitable for submicron particulate removal. Except for one plant, the elemental phosphorus industry uses this type of collector for controlling very fine particulates associated with furnace taphole operations. This collector uses a venturi-shaped construction to establish throat velocities, which may range from 60 to 120 m/min (200 to 400 ft/s). Water is supplied at or ahead of the throat through piping or jets at a range of 19 to 57 l/m (5 to 15 gpm) per 28.3 SCMM (1000 SCFM) of gas.

The collection mechanism of the venturi is impaction. As water droplets accelerate to gas velocity in the expanding section of the venturi, the noncaptured dust overtakes the droplets at decreasing relative velocity. Capture of fine dust by fine droplets through diffusion is increased as relative velocities of dust and droplet approach zero. As with wet collectors in general, the collection efficiency of the venturi increases with higher pressure drops. Different pressure drops are achieved by designing the venturi throat for selected gas velocities. Some venturi collectors have adjustable throats that allow for a range of pressure drops with a given volume or for maintaining a constant pressure drop when the volume is variable. Systems are available with throat pressure drops as low as 13 cm (5 in) and as high as 254 cm (100 in) W. G. The mixture of gases, fume-dust agglomerates, and dirty water is fed into a centrifugal type separator with velocities further reduced, and the dust and water particles are removed as a slurry (Figure 4-9). There are literally dozens of different venturi designs, but for fine particulate removal, pressure drops will be anywhere from 50 to 190 cm (20 to 75 in) W. G.

Wet centrifugal collectors (Figure 4-9) comprise a large portion of the commercially available designs. This type of device uses centrifugal force to accelerate dust particles and impinge them upon a wetted collector surface. Water rates are usually 7.5 to 19 l/m (2 to 5 gpm) per 28.3 SCMM (1000 SCFM) of gas cleaned. Water distribution can be from nozzles, gravity flow, or induced water pickup. Pressure drop is on the order of 5 to 15 cm (2 to 6 in) W. G. As a group, these collectors are more efficient than the chamber type. Some are available with different numbers of impingement sections while others contain multiple collecting tubes. These relatively small tubes provide higher collection efficiency in the same manner as the multitube small diameter cyclones and are more efficient than large diameter cyclones of the dry mechanical group.

One common type of wet centrifugal collector used by at least half of the existing elemental phosphorus plants is the American Air Filter Type R Rotoclone. This device is most commonly associated with nodule sizing operations and furnace feed material handling and transfer operations. It consists of a series of specially designed double-inlet tubes each of which handles 127 ACMM (4500 ACFM) at 15 cm (6 in) W. G. collector resistance. The resistance through the tubes varies proportionally to the gas flow. Each tube consists of three major parts: inlet cone, barrel and discharge cone. The tubes are placed in a 3-compartment housing consisting of a collection section, water eliminator section and clean air plenum.

The chamber or spray tower is another type of wet collector commonly used at elemental phosphorus plants, most frequently with calciner offgas treatment and furnace offgas condensers. These devices have a round or rectangular chamber into which water is introduced via spray nozzles. There are many variations of design but the principal mechanism is impaction of dust particles on the liquid droplets created by the nozzles. These droplets are separated from the air stream by centrifugal force or impingement on water eliminators. Pressure drop is relatively low at 1.25 to 4 cm (0.5 to 1.5 in) W. G. This type of collector generally uses low-pressure supply water and operates in the lower efficiency range of wet collectors. Where water pressure is supplied under high pressure, collection efficiency



WET CENTRIFUGAL

VENTURI SCRUBBER

Symbols	Parts
A	Clean air outlet.
B	Entrainment separator.
C	Water inlet.
D	Impingement plates.
E	Dirty air inlet.
F	Wet cyclone for collecting heavy material
G	Water and sludge drain.

Figure 4-9. Wet Type Dust Collectors.

reaches the upper range of wet collectors. Water requirements are reasonable, with a maximum of about 19 l/m (5 gpm) per 28.3 SCMM (1000 SCFM) of gas. Fogging types using high water pressure may require twice as much water.

A relatively new type of wet collector uses a wetted fiber glass filter mat installed over a perforated filtration drum. The Andersen-2000 CHEAF cleanable high efficiency air filter is a wet collector that can be used to remove a mixture of water soluble and water insoluble particulate matter. (See Appendix B for detailed technical information). The water soluble particulate matter is collected on the filter mat and is then washed through with a scrubbing liquid introduced from spray nozzles mounted around the filtration drum. The insoluble particulate matter is retained in the filter and as the concentration in the filter mat builds to the point where the differential pressure becomes excessive and flow begins to degrade, the filter mat is advanced automatically to expose fresh filter media to the gas stream. By advancing the filter mat in small increments, a constant differential pressure is maintained and a constant gas flow rate results. This type of system is used at the FMC elemental phosphorus plant for controlling particulates in taphole fumes and in vent gas from phosphorus handling operations. Typical differential pressure is 88 cm (35 in) W. G. for these applications. It is estimated that the cost of the filter media consumed and the cost of electrical power for the induced draft fan results in a substantially lower operating cost than for a comparable performance scrubbing system. Total particulate removal efficiency for existing elemental phosphorus plant applications is approximately 99.5 percent.

The packed tower collector is essentially a contact bed through which gases and liquids pass either concurrently, counter-currently, or in cross-flow. These collectors are used primarily for removing gas vapor and mist. They will capture solid particulates but are not generally used because dust will plug the packing requiring unreasonable maintenance. The use of this type of collector in the elemental phosphorus industry is rare.

In addition to particulate control, mist elimination is required in some emission control techniques associated with the elemental phosphorus plant. There are two basic types of drop or mist removal devices: an impingement separator and a unit that operates on the principle of Brownian movement or diffusion. The impingement type separator removes droplets or mist from a wet gas stream by impinging them on a surface. Impingement separators comprise dozens of different designs, but their basic configuration is either a mesh of wire or some similar material or a series of plates designed to change the direction of a gas stream several times. Impingement type separators will remove droplets down to approximately 10 μm in diameter at about 99 percent efficiency. Velocities through impingement type separators are usually maintained between 1.5 and 9 m/s (5 to 30 ft/s), and separators are generally arranged in the gas stream horizontally so that the gas flows vertically up through the separator. Thus, droplets removed fall back into the entering gas stream. This type of mist separator has a very low pressure drop of about 2.5 to 5 cm (1 to 2 in) W. G.

The other type of mist separator is the fiber bed unit made of very fine fiberglass, polyester, or Teflon fibers packed to a high density within the bed. This type of mist separator removes droplets by Brownian diffusion. The droplets entering the fiber bed will tend to follow the tiny fibers until coalescing occurs near the bottom of the unit (Figure 4-10). This type of mist eliminator is capable of removing droplets or mists down to 0.3 μm at efficiencies up to 99 percent. It differs from the impingement type separator not only in its method of operation but also in its pressure drop. The pressure drop through a fiber bed mist eliminator will be from 15 to 40 cm (6 to 16 in) W. G., depending upon the flow and efficiency required. The mist eliminator of the fiber bed type is not generally recommended for streams containing particulates. But if the particulates are water soluble and in relatively low concentrations, the mist eliminator may be used. One type of fiber bed unit used at several elemental phosphorus plants is a Clermont aerosol candle filter mist eliminator. (See Appendix B for detailed technical information). This system is used on furnace condenser offgas and removes essentially 100 percent of all particles larger than 3 μm in diameter and 99.5 percent of particles smaller than 3 μm.

4.2.4 Costs

The costs for airborne emission control equipment, especially on an installed basis, are difficult to estimate. Cost comparisons are complicated unless all factors included or not included are known and carefully evaluated. Factors that make useful cost estimates difficult to furnish include:

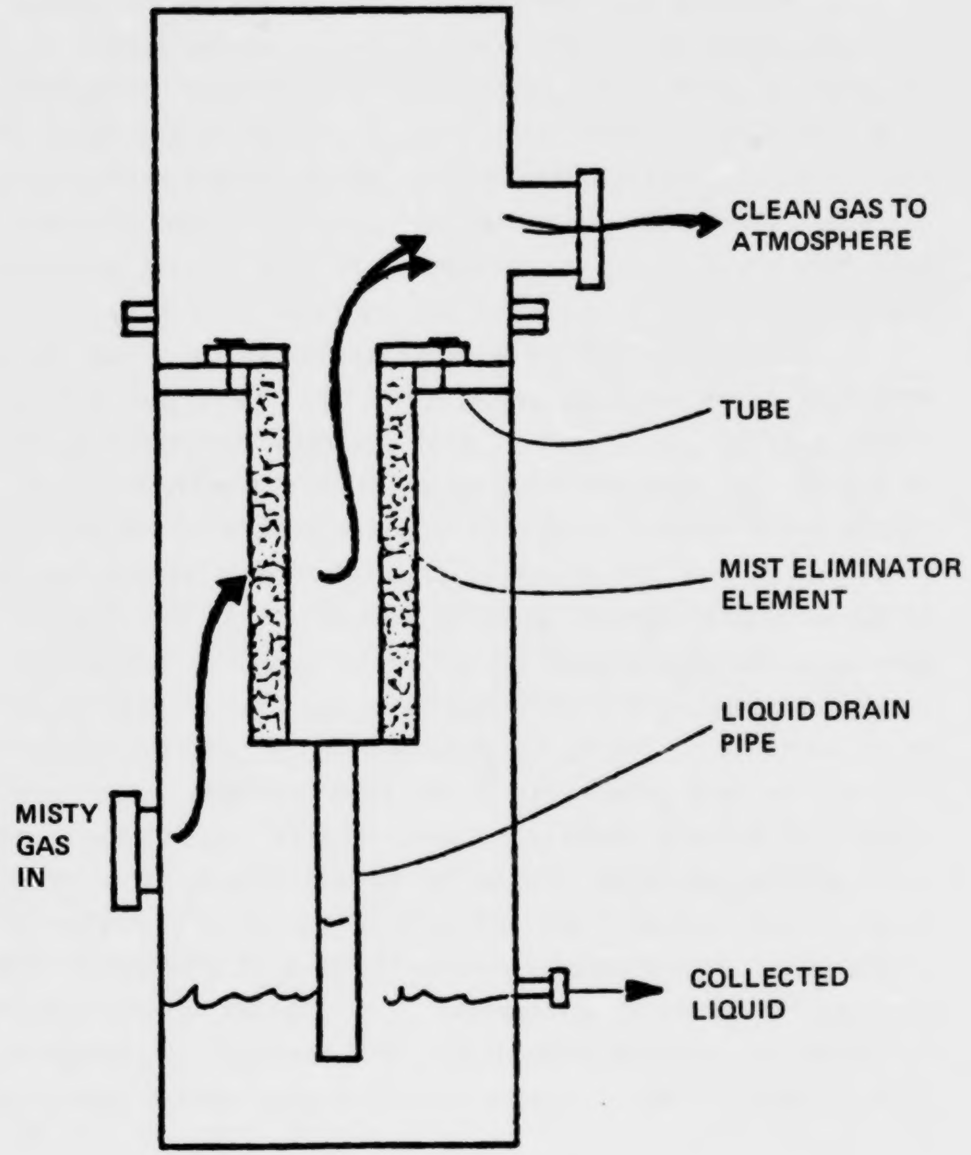

CLEAN GAS TO ATMOSPHERE
TUBE
MIST ELIMINATOR ELEMENT
LIQUID DRAIN PIPE
MISTY GAS IN
COLLECTED LIQUID

Figure 4-10. Fiber Bed Mist Eliminator.

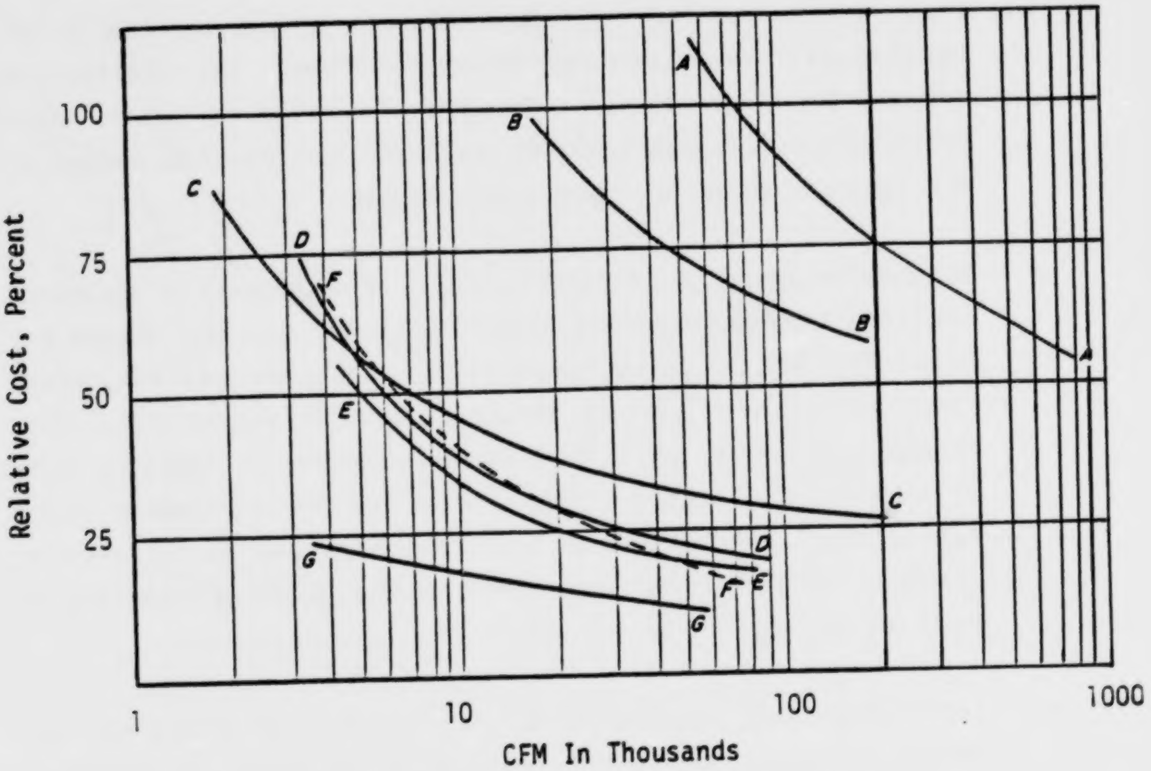
- Price versus Capacity - All dust collector prices per CFM of gas handled will vary with the volume involved. The smaller the volume, the higher the cost per CFM. The breakeven point, where price per CFM cleaned tends to level off, varies with design, as the typical curves in Figure 4-11 indicate.

- Accessories Included - Careful analysis of components of equipment included is very important. Some collector designs include exhaust fan, motor, drive, and starter. In other designs, these items and their supporting structure must be secured from other sources. Likewise, while dust storage hoppers are integral parts of some dust collector designs, they are not provided in other types. Duct connections between elements may be included or omitted. Recirculating water pumps and/or settling tanks may be required and may not be included in the equipment price.

- Installation Cost - Installation cost can equal or exceed the cost of the collector, depending on method of shipment and location. Cost can be measurably influenced by the need for water and drain supply, special or extensive electrical work, and expensive material handling equipment for collection material disposal. Waste handling equipment will often be a variable decreasing in cost per CFM as the volume of gas to be cleaned increases.

- Special Construction - Prices shown in any tabulation must assume standard or basic construction. Increase in cost for corrosion resisting material, special fabrics, insulation and/or weather protection for outdoor installations, can introduce a multiplier one to four times standard construction cost.

An attempt was made to estimate total capital costs and annual operating and maintenance costs associated with airborne emission control systems for the elemental phosphorus industry on a plant-specific basis. These costs are tabulated in Table 4-3 and are based on both actual and estimated cost information. Capital costs are adjusted to 1983 dollars on



A. High voltage precipitator (minimum cost range)
B. Continuous duty high temperature fabric collector (2:1)
C. Continuous duty reverse pulse (8:1)
D. Wet collector
E. Intermittent duty fabric collector (2:1)
F. Low voltage precipitator
G. Cyclone

Note 1: Cost based on collector section only. Does not include ducts, dust disposal devices, pumps, exhausters or other accessories not an integral part of the collector.

Note 2: Price of high voltage precipitator will vary substantially with applications and efficiency requirements. Costs shown are for dust applications where velocities of 200 to 300 fpm are normal.

Note 3: Numbers in parentheses are air-to-cloth ratios.

Figure 4-11. Relative Cost Information for Dust Collection Equipment [3].

Table 4-3. Estimated Plant Airborne Emission Control Equipment Costs in Millions of Dollars.

Plant	Capital Costs[1,2]	Annual[2] Operating Costs	Annual[2] Maintenance Costs
FMC - ID	23.80	1.31	1.16
Stauffer Chemical - MT	10.81	0.68	0.54
Stauffer Chemical - TN	7.17	0.91	0.35
Stauffer Chemical - FL	3.35	0.67	0.27
Monsanto - TN	8.02	1.62	0.56
Monsanto - ID	43.09	4.02	0.31
Mobil Chemical - FL	2.16	0.50	0.20
Occidental Chemical - TN	3.69	0.66	0.44

(1) Capital costs adjusted to 1983 dollars based on the Chemical Engineering Plant Cost Index [5].

(2) Developed using the methodology presented in Ref. [6] and adjusted to 1983 dollars.

the basis of the Chemical Engineering Plant Cost Index [5]. Estimated costs are based on methodology discussed in Reference [6] and adjusted to 1983 dollars. Individual costs for specific equipment are itemized in Section 4.3

4.3 PLANT AIRBORNE EMISSION CONTROL TECHNIQUES AND EQUIPMENT

The airborne emission control techniques and equipment used by each elemental phosphorus plant and their efficiencies are summarized in Table 4-4 by major processes. In nearly all instances, the particulate removal efficiencies given are equipment design efficiencies. In some instances, however, efficiencies are based on actual operating or test data. Efficiencies are stated as the percentage of total particulates by weight removed from a process stream unless otherwise stated. Where both design and operating efficiency data were available, agreement was usually good. Only relatively high-efficiency techniques and equipment responsible for control of finer particulates are summarized in Table 4-4; equipment items such as low-efficiency cyclones or other mechanical collectors normally used for large particulates are described as necessary in the following plant specific sections. In general, the low-efficiency equipment used for large particulates is identified but not described in technical detail. The plant specific high-efficiency control equipment used at each potential emission source is presented in technical detail.

Table 4-4. Summary of Plant-Specific Airborne Emission Control Techniques and Equipment(1).

Plant / Process	FMC	Stauffer Chemical-MT	Stauffer Chemical-TN	Stauffer Chemical-FL	Monsanto-TN	Monsanto-ID	Mobil Chemical	Occidental Chemical
Ore/calciner feed handling	Standard Havens pulse filters (99.8)	Turbulaire Type D wet scrubber (98)	None	American Air Filter Amer-pulse bag filters (99+)	None	None	Hydronics wet venturi scrubber (90)	None
Calciner	"Disc-slinger" wet scrubbers (85)	Spray tower scrubber (97.2) Fluid Ionic Hydro-Precipitrol wet ESP (99)	Spray tower scrubber (99.8)	Spray tower scrubber (99)	Spray tower scrubber (99-99.5)	Spray tower scrubber (99.9)	Hydronics vertical leg scrubber (50,+10μm) Spray tower cyclone separator (two in series) (80,+3μm)(90)	Jet venturi scrubber (N/A) Spray tower scrubber (inactive) (N/A)
Calciner cooler	Baffled settling chambers (65)	Turbulaire Type D wet scrubber (98)	Spray tower scrubber (99)	Turbulaire Type D wet scrubber (98.8)	Jet eductor scrubber (99.6-99.7)	Spray tower scrubber (98.8)	None	Jet venturi scrubber (N/A)
Nodule sizing	Dustex pulse-reverse air filter (N/A)(2)	Turbulaire Type D wet scrubber (98)	Spray tower scrubber (98.8)	American Air Filter Type R Rotoclone wet centrifugal collector (99,+10μm;90,+2μm)	American Air Filter Type R Rotoclone wet centrifugal collector (98)	Wet venturi scrubber (99.98)	Sly Multi-Seal Dynaclone bag filter (99.9,+½μm)	American Air Filter Type R Rotoclone wet centrifugal collector (98)
Coke handling/drying	Mikropul pulse filter (99.0)	Turbulaire Type D wet scrubber (98)	Turbulaire Type D wet scrubber (97)	None	Baghouse filters (N/A) Wet venturi scrubber 99+	Baghouse filter (99.9) Spray tower scrubber (99.6)	American Air Filter Type R Rotoclone wet centrifugal collector (98) Kimre tail gas scrubber (99,+3μm)	Flex-Kleen pulse filter (N/A) Ducon VVO wet venturi scrubber (N/A)

Table 4-4. Summary of Plant-Specific Airborne Emission Control Techniques and Equipment(1) (Cont'd).

Process \ Plant	FMC	Stauffer Chemical-MT	Stauffer Chemical-TN	Stauffer Chemical-FL	Monsanto-TN	Monsanto-ID	Mobil Chemical	Occidental Chemical
Feed proportioning	Mikropul pulse filter (99.0)	Turbulaire Type D wet scrubber (98)	Turbulaire Type D wet scrubber (93)	American Air Filter Fabri-Pulse bag filter (N/A)	Lear Siegler/Luhr and American Air Filter bag filters (99.95-99.97)	Baghouse filter (99.9)	Sly Multi-Seal Dynaclone bag	Ducon VVO wet venturi scrubber (N/A)
Burden area	BAHCO cassette/pulse filters (99.9)	None (Enclosed pressurized system)	Turbulaire Type D wet scrubber (97-98.9)	American Air Filter Type R Rotoclone wet centrifugal collector (95)	Baghouse filter (99.94-99.96)	Baghouse filter (99.9)	None	American Air Filter Type R Rotoclone wet centrifugal collector (98)
Furnace tap-hole fume collector	Medusa wet venturi scrubbers (65,P_2O_5) Andersen-2000 filter media scrubber (99.5)	Fluid Ionic Hydro-Precipitrol wet ESP (80) Wet venturi scrubber (standby) (N/A)	Wet venturi scrubber (92-97)	Wet venturi scrubber (80;95,P_2O_5)	Wet venturi scrubber (N/A)	Wet venturi scrubber (95)	Hydronics wet venturi scrubber (98,+1μm)	Air Pollution Industries wet venturi scrubber (N/A)
Furnace offgas	Primary water spray condenser (N/A) Secondary water spray condenser (94)	Water spray condenser (N/A)	Water spray condenser (N/A)	Water spray condenser (90,+10μm)	Water spray condenser (99.99) Wet scrubber (99.5)	Water spray condenser (N/A)	Vertical nozzle spray scrubbers (two in series) (N/A)	Water spray condensers (two in series) (N/A)
Phosphorus handling/processing	Andersen-2000 filter media scrubber (99.5)	Clermont wet scrubber (for roasters) (99)	Water spray condenser (for roasters) (N/A)	Clermont wet scrubber (99.5)	None	None	None	American Air Filter Kinpactor wet venturi scrubber (N/A)

(1) Values in parentheses are total particulate removal design efficiencies for specific airborne emission control techniques and equipment. Where particle sizes or type of particulate are identified, efficiency refers to all particulates greater than the specified size.

(2) N/A - not available.

4.3.1 FMC Plant - Pocatello, Idaho

4.3.1.1 Techniques and Equipment

Point sources of airborne emissions from the FMC plant were identified in Table 3-8 together with a general listing of the associated emission control equipment. Additional technical information is summarized in Table 4-5 for the major emission control systems. The FMC plant operates with a state permit limiting particulate emissions and according to the regulations of the Idaho Department of Health and Welfare - Division of Environment. When visible emissions from the baghouses and Andersen particulate control systems exceed 5 percent opacity, FMC is required to initiate appropriate corrective action to reduce the opacity to 5 percent or below. Point sources of airborne emissions required to comply with applicable limitations and standards are either stack tested annually for compliance certification or monitored for compliance by visual opacity readings.

Ore Crushing and Transfer System

Phosphate ore stockpiled at the plant is screened and crushed before being fed to the briquetting process. Dust generated by these operations is collected by three shale baghouses (filters) that vent three separate building enclosures. The east shale baghouse collects dust from conveyer belts, transfer points, and dozer traps between the ore stockpile and crushing and screening. The middle shale baghouse collects dust from crushing and screening. The west shale baghouse collects dust from the ore handling and transfer points between crushing and screening and the briquetting operation. Detailed design data for these baghouses are summarized in Table 4-6.

When visible emissions exceed 5 percent opacity, corrective action is implemented in accordance with established operation and maintenance manual procedures. Baghouse efficiency is 99.8 percent.

Enclosed Briquetting Operation

Briquetting takes place in an enclosed building and does not have any related point sources of airborne emissions. The moisture content (11-14 percent) of the ore normally prevents emission of fugitive dust from this operation.

Table 4-5. FMC Airborne Emission Control Techniques and Equipment(1).

Emission Point	Emission Source	Type of Equipment	Maintenance(2)	Dust Disposal	Scrubbing Media
East shale baghouse	Ore handling, transfer points, dozer traps	Standard Havens pulse filter	Monthly PM(3), CM(4) as needed	Pneumatically conveyed to silo, recycled back to process	-
Middle shale baghouse	Ore crushing and screening operation	Standard Havens pulse filter	Monthly PM, CM as needed	Pneumatically conveyed to silo, recycled back to process	-
West shale baghouse	Ore handling, transfer points	Standard Havens pulse filter	Monthly PM, CM as needed	Pneumatically conveyed to silo, recycled back to process	-
Calciner scrubbers (two per calciner, four total)	Ore calciner offgas	FMC-designed disc-slinger wet scrubber	Monthly PM, CM as needed	-	Recycled process water
Calciner coolers (one per calciner)	Ore calciner cooler offgas	Baffled settling chamber	Monthly pm, cm as needed	Pneumatically conveyed to silo, recycled back to process	-
Nodule stockpile baghouse	Nodule stockpile ladders, nodule transfer points	Standard Havens pulse filter	Monthly PM, CM as needed	Pneumatically conveyed to silo, recycled back to process	-
North nodule reclaim baghouse	Nodule transfer points, calciner discharge	Dustex momentum pulse-reverse air filter	Monthly PM, CM as needed	Pneumatically conveyed to silo, recycled back to process	-
South nodule reclaim baghouse	Nodule reclaim operation	Dustex momentum pulse-reverse air filter	Monthly PM, CM as needed	Pneumatically conveyed to silo, recycled back to process	-
East and west nodule baghouses	Nodule weigh-feeders and conveyer belts in proportioning operation	Mikropul pulse filter	Weekly PM, CM as needed	Pneumatically conveyed to silo, recycled back to process	-
Coke handling baghouse	Coke unloading and conveying	Mikropul pulse filter	Weekly PM, CM as needed	Pneumatically conveyed to silo, recycled back to process	-

Table 4-5. FMC Airborne Emission Control Techniques and Equipment(1). (Continued)

Emission Point	Emission Source	Type of Equipment	Maintenance(2)	Dust Disposal	Scrubbing Media
Silo baghouse	Burden conveying outside furnace building	Mikropul pulse filter	Weekly PM, CM as needed	Pneumatically conveyed to silo, recycled back to process	-
East and west burden baghouses	Burden conveying and bins inside furnace building	BAHCO cassette/pulse filter	Monthly PM, CM as needed	Pneumatically conveyed to silo, recycled back to process	-
Primary furnace fume scrubbers (two per furnace, eight total)	Furnace slag and ferrophosphorus tapping operations	Medusa wet venturi scrubbers	Monthly PM, CM as needed	-	Recycled process water
Secondary furnace fume scrubbers (one per furnace, four total)	Furnace slag and ferrophosphorus tapping operations	Andersen-2000 "CHEAF" filter media scrubber	Monthly PM, CM as needed	-	Automatically advanced fiberglass filter media
Slurry drying electrostatic precipitator	Slurry drying operation	Buell dry plate electrostatic pricipitator	CM upon periodic inspection	Collected and added to prills as product	-
Slurry drying wet scrubber	Slurry drying process	Medusa wet venturi scrubber	CM upon periodic inspection	-	Recycled process water
Phosphorus loading dock scrubber	Phosphorus storage and loading area	Anderson-2000 "CHEAF" filter media scrubber	Monthly PM, CM as needed	-	Automatically advanced fiberglass filter media
Furnace offgas condensers (four primary, one secondary)	Furnace offgas CO	FMC-designed water spray condenser	Biweekly PM, CM as needed	-	Fresh water plus recycled process water

(1) Information obtained from Ref. [7] and from FMC by SAI staff during visit to FMC plant on November 1-2, 1982.

(2) Information obtained from FMC by SAI staff during visit to FMC plant on November 1-2, 1982.

(3) PM - Preventive Maintenance.

(4) CM - Corrective Maintenance.

Table 4-6. FMC Ore Crushing and Transfer System Baghouses(1).

Emission Point	Mfr. & Model No.	Gas Flow ACMM (ACFM)	Efficiency(2) (%)	Air to Cloth(3) Ratio	Type of Bag	$\Delta P^{(2)}$ cm (in) W.G.
East shale baghouse	Standard Havens Delta Mark I, Model #DM-12/8	142 (5000)	99.8	4.6/1	Polypropylene felt, 16 oz.	10 ± 5 (4 ± 2)
Middle shale baghouse	Standard Havens Alpha/Mark I Size 12	283 (10,000)	99.8	4.4/1	Polypropylene felt, 16 oz.	13 ± 5 (5 ± 2)
West shale baghouse	Standard Havens Alpha/Mark I	481 (17,000)	99.8	4.2/1	Polypropylene felt, 16 oz.	13 ± 5 (5 ± 2)

(1) Information obtained from Ref. [7] and from FMC by SAI staff during visit to FMC plant on November 1-2, 1982.

(2) Information obtained from FMC by SAI staff during visit to FMC plant on November 1-2, 1982.

(3) Air-to-cloth ratio normally expressed in ACFM/ft^2 filter area.

Calciner-Coolers

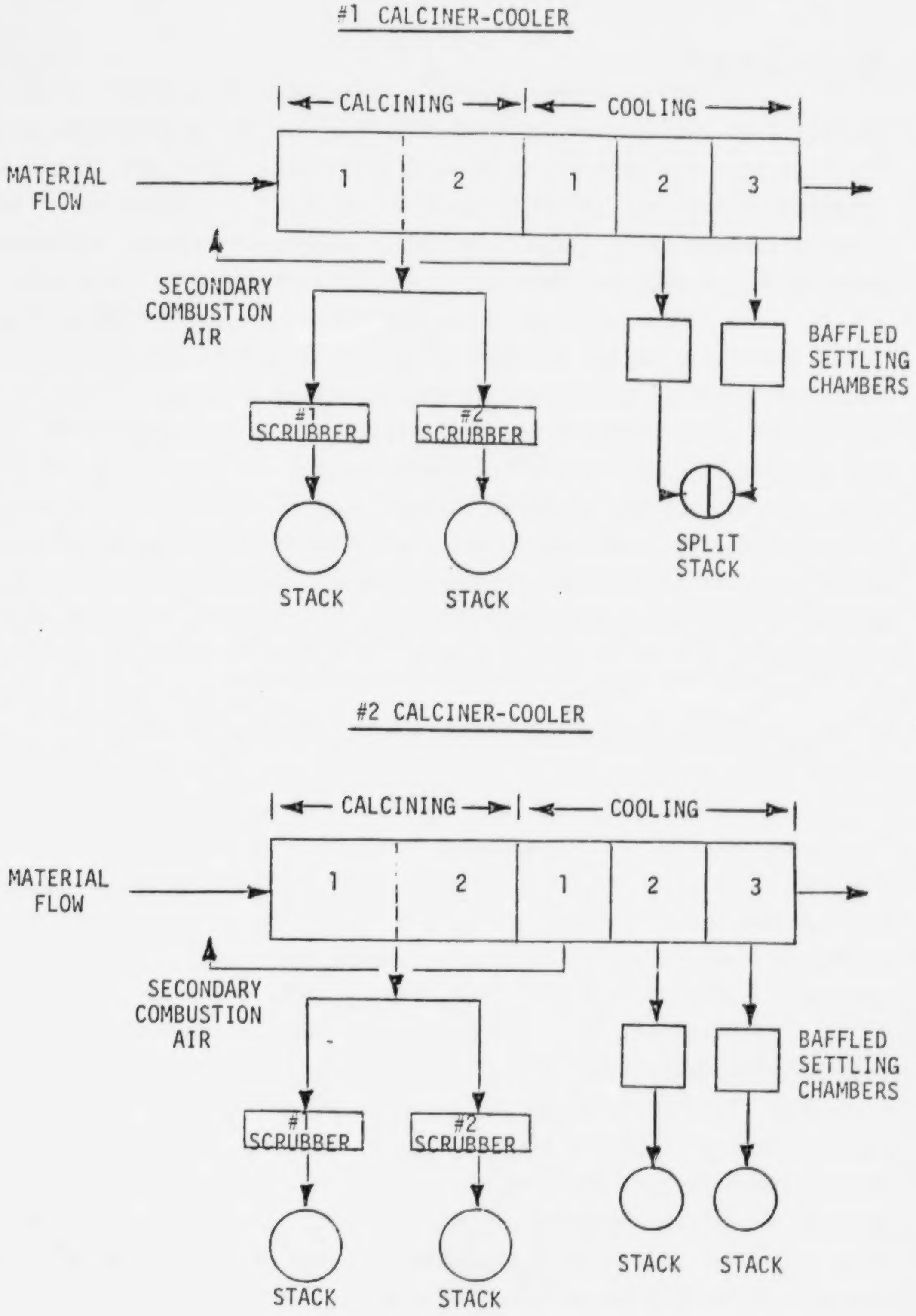
FMC operates two traveling grate calciner-coolers in parallel. The calciner-coolers are divided into five hooded sections as shown in Figure 4-12. The offgases from each calciner section are vented into a common duct that splits the flow to two parallel wet scrubbers. The calciner scrubbers (four total) are FMC-designed disc-slinger wet scrubbers. Detailed design data for these scrubbers are summarized in Table 4-7.

The gases collected from the first cooling section of the calciners are routed to the calciner burners as secondary combustion air. The gases collected in the second and third cooling sections are sent through baffled settling chambers and then discharged to the atmosphere. The #1 calciner cooling sections discharge through a split stack and the #2 calciner cooling sections discharge through separate stacks. Fifteen to twenty percent of the gas discharge to the stack from the second cooling section of the #2 calciner is diverted for heat recovery to heat various ore transfer points. A portion of the particulates is diverted from the stack back into the process.

Nodule Stockpile, Reclaiming, Proportioning, and Coke Handling

The nodules from the calcining operation are either sent directly to the proportioning building or stockpiled. When the nodules are reclaimed from the stockpiles, the emissions from the transfer and screening operation are controlled by the north and south nodule reclaim baghouses. A baghouse for the stockpile ladders is also utilized. The conveyer system is enclosed, and the transfer points and screens are hooded and vented to these baghouses. Detailed data for these baghouses are summarized in Table 4-8.

In the proportioning building, streams consisting of calcined nodules, coke, and silica rock are proportioned for conveying to the furnace feed bins. The conveying system, transfer points, and bin discharge points are hooded and vented to four baghouses: the east and west nodule baghouses, the coke handling baghouse, and the silo baghouse. All but the silo baghouse are located together on the north side of the proportioning building, with the coke handling baghouse in the middle. The west nodule baghouse collects from various discharge and transfer points and the lower portion of the proportioning building. The east nodule baghouse collects



#1 CALCINER-COOLER

#2 CALCINER-COOLER

CALCINING
COOLING
MATERIAL FLOW
1
2
1
2
3
SECONDARY COMBUSTION AIR
BAFFLED SETTLING CHAMBERS
#1 SCRUBBER
#2 SCRUBBER
STACK
STACK
SPLIT STACK
CALCINING
COOLING
MATERIAL FLOW
1
2
1
2
3
SECONDARY COMBUSTION AIR
BAFFLED SETTLING CHAMBERS
#1 SCRUBBER
#2 SCRUBBER
STACK
STACK
STACK
STACK

Figure 4-12. FMC Plant Calciner - Coolers [6].

Table 4-7. FMC Calciner-Cooler Emission Control Equipment(1).

Emission Point	Mfr. & Model No.	Gas Flow ACMM (ACFM)	Efficiency(2) (%)	Water Rate l/s (gpm)	ΔP cm (in) W.G.
#1 calciner - #1 scrubber	FMC-designed disc-slinger wet scrubber	3400 (120,000)	85	11 (175)	7.5±2.5 (3±1)
#1 calciner - #2 scrubber	FMC-designed disc-slinger wet scrubber	3400 (120,000)	85	11 (175)	7.5±2.5 (3±1)
#2 calciner - #1 scrubber	FMC-designed disc-slinger wet scrubber	3400 (120,000)	85	11 (175)	7.5±2.5 (3±1)
#2 calciner - #2 scrubber	FMC-designed disc-slinger wet scrubber	3400 (120,000)	85	11 (175)	7.5±2.5 (3±1)
#1 calciner - #1 cooler	Baffled settling chamber	2465 (87,000)	65	-	N/A
#1 calciner - #2 cooler	Baffled settling chamber	2465 (87,000)	65	-	N/A
#2 calciner - #1 cooler	Baffled settling chamber	3400 (120,000)	65	-	N/A
#2 calciner - #2 cooler	Baffled settling chamber	3400 (118,000)	65	-	N/A

(1) Information obtained from Ref. [7] and from FMC by SAI staff during visit to FMC plant on November 1-2, 1982.

(2) Information obtained from FMC by SAI staff during visit to FMC plant on November 1-2, 1982.

(3) N/A - not available.

Table 4-8. FMC Nodule Stockpile and Feed Proportioning Area Baghouses(1).

Emission Point	Mfr. & Model No.	Gas Flow(2) ACMM (ACFM)	Efficiency(2) (%)	Air to Cloth(2) Ratio	ΔP cm (in) W.G.
Nodule stockpile baghouse	Standard Havens Alpha/Mark I	566 (20,000)	99.8	4.0/1	10±5 (4±2)
North nodule reclaim baghouse	Dustex Momentum Pulse-Reverse Air Model 2118-20	736 (26,000)	N/A(3)	5.4/1	15±5 (6±2)
South nodule reclaim baghouse	Dustex Momentum Pulse-Reverse Air Model 2118-20	736 (26,000)	N/A	4.9/1	15±5 (6±2)
East nodule and West nodule baghouses, each	Mikropul-Pulsejet Model Pulsair 263	595 (21,000)	99.0	6.1/1	15±5 (6±2)
Coke handling baghouse	Mikropul-Pulsejet Model Pulsair 263	595 (21,000)	99.0	7.1/1	15±5 (6±2)
Silo baghouse	Mikropul-Pulsejet Model Pulsair 263	765 (27,000)	99.0	5.9/1	23±10 (9±4)

(1) Information obtained from Ref. [7] and from FMC by SAI staff during visit to FMC plant on November 1-2, 1982.

(2) Information obtained from FMC by SAI staff during visit to FMC plant on November 1-2, 1982.

(3) N/A - not available.

from certain discharge and transfer points and from the top of the bins. The coke baghouse collects from various coke unloading and conveying points. The silo baghouse collects from burden conveyer and transfer points outside the furnace building. Detailed design data for these baghouses are summarized in Table 4-8.

Burden Area

The major features of the burden area are a burden feed system consisting of a computerized shuttle conveyer system and 20 feed bins (5 per furnace), an enclosed burden area above the furnace building, and two baghouses to collect dust from conveyer belts, transfer points, and feed bins. The enclosed burden area is divided into four compartments (one over each furnace) with two pickup ducts per compartment. These compartments are vented to two BAHCO east and west burden baghouses. The BAHCO baghouses represent relatively new technology, and each has 88 modular cassettes that can be changed individually. The conveying system and transfer points are vented to the silo baghouse. Detailed data for the east and west burden baghouses are summarized in Table 4-9.

Furnace Tapping Operations

The burden mixture is gravity fed to one of four electric arc furnaces. The ferrophosphorus and slag tapping operations and emission control systems are essentially the same for each furnace. Each furnace has an east and west taphole for slag and an east and west taphole for ferrophosphorus. The tapholes and the slag runners on each side of the furnace are vented to two parallel Medusa wet venturi action scrubbers (8 total) that collect fugitive fumes (primarily P_2O_5). These scrubbers are a primary scrubbing step and discharge to a common duct. Taphole fumes typically have a composition of 40 percent P_2O_5, 40 percent tar volatiles, and 20 percent calcium silicates. The mean particle diameter of the P_2O_5 is approximately 0.6 μm [8]. The Medusa scrubber is not capable of high collection efficiencies with fine particles. Thus, as a secondary step, the fumes are treated by an Andersen-2000 "CHEAF" filter media scrubbing system (4 total).

The Andersen-2000 filter media scrubbing system draws the fumes through a wetted filter mat. As the particulates collect on the filter mat, the mat becomes plugged and the pressure drop increases. A pressure dif-

Table 4-9. FMC Burden Area Baghouses(1).

Emission Point	Mfr. & Model No.	Gas Flow(2) ACMM (ACFM)	Efficiency(2) (%)	Air to Cloth Ratio	ΔP cm (in) W.G.
East burden baghouse	BAHCO Systems, Inc. Model JSA 88	2265 (80,000)	99.9	4.2/1	18±5 (7±2)
West burden baghouse	BAHCO Systems, Inc. Model JSA 88	2265 (80,000)	99.9	4.2/1	18±5 (7±2)

(1) Information obtained from Ref. [7] and from FMC by SAI staff during visit to FMC plant on November 1-2, 1982.

(2) Information obtained from FMC by SAI staff during visit to the FMC plant on November 1-2, 1982.

ferential control circuit automatically advances the filter mat to maintain a relatively constant pressure differential and gas flow. The normal differential pressure is about 86 cm (34 in) W. G. and the filter is advanced when the differential pressure reaches about 100 cm (40 in) W. G. Normally, a 60-m (200-ft) roll is replaced every 20 hours. Detailed design data for the Andersen systems and Medusa scrubbers are summarized in Table 4-10.

Slurry Handling

Dust and other particulates from the furance CO offgas are removed in an electrostatic precipitator. These solids are slurried and then fed to a fluid drying process. The offgases from the fluid bed dryer are cleaned in a two-stage Buell dry plate electrostatic precipitator and Medusa scrubber operating in series. Detailed design data for this system are summarized in Table 4-11.

Phosphorus Loading Dock

The phosphorus loading dock area contains a series of intermittent operations, which include phosphorus loading and sludge processing. Emissions from this area can result from the burning of elemental phosphorus, which forms submicron P_2O_5 smoke. An Andersen-2000 "CHEAF" filter media scrubber is used to control emissions in this area. Data for this system are identical to that shown in Table 4-10 for the Andersen-2000 taphole unit except that system gas flow is 708 ACMM (25,000 ACFM) and ΔP is 89 ± 13 cm (35 ± 5 in) W.G.

Furnace Phosphorus Sumps

The phosphorus from the primary condenser of each furnace is collected in a sump under the furnace. To prevent CO and phosphine (PH_3) buildup, the sumps are vented to the Medusa taphole fume scrubbers.

CO Flare and Flare Pit

FMC operates an elevated CO flare with natural gas pilot to burn excess CO produced by the furnaces. The furnace offgases from each furnace are treated in an electrostatic precipitator for dust removal followed by a primary spray tower condenser. Most of the phosphorus is removed in the primary condenser and transported to phosphorus storage under a water seal.

Table 4-10. FMC Furnace Taphole Fume Scrubbers(1).

Emission Point	Mfr. & Model No.	Gas Flow(2) ACMM (ACFM)	Efficiency (%)	Water Rate l/s (gpm)	ΔP cm (in) W.G.
Primary furnace fume scrubbers, furnaces 1 through 4 (each)	Two Medusa wet venturi action scrubbers	566 ea. (20,000)	65 (P_2O_5)	0.6 ea. (10)	20±2.5 (8±1)
Secondary furnace fume scrubbers, furnaces 1 through 4 (each)	Andersen-2000 "CHEAF", Model DF-44	1133 (40,000)	99.5	0	86±13 (34±5)

(1) Information obtained from Ref. [7] and from FMC by SAI staff during visit to FMC plant on November 1-2, 1982.

(2) Information obtained from FMC by SAI staff during visit to FMC plant on November 1-2, 1982.

Table 4-11. FMC Furnace Offgas Dust Slurry Handling Control System [7].

Emission Point	Mfr. & Model No.	Gas Flow ACMM (ACFM)	Efficiency (%)	Water Rate l/s (gpm)	ΔP cm (in) W.G.)
Slurry drying electrostatic precipitator	Buell Dry Plate	2158	N/A(1)	0	2.5 (1)
Slurry drying wet scrubber	Krebbs Medusa Model 2-MRG 275-C	2158	N/A	3.2 (50)	22±2.5 (8.5±1)

(1) N/A - not available

A single secondary condenser is used to remove the remaining phosphorus from the gases leaving the four primary condensers. The temperature is reduced to about 28°C (82°F). Since this temperature is below the melting point of elemental phosphorus (44°C), the spray nozzles tend to plug and the system needs to be periodically flushed to melt and remove accumulated phosphorus. During hot flushes of the secondary condenser system, any elemental phosphorus contained in the line is melted and moved toward the flare pit by the CO gas. The phosphorus is collected upstream of the flare pit by an eductor system which returns the phosphorus to storage. The gas flow rate is controlled during the hot flush to prevent phosphorus from reaching the flare pit so that visible emissions are controlled. The hot flushes last for about four hours and usually occur twice every two weeks.

The secondary condenser is an FMC-designed water spray condenser with gas flow of 680 ACMM (24,000 ACFM), 94.0 percent efficiency for particulate removal, 126 l/s (2000 gpm) water flow, and a ΔP of 30 cm (12 in) W.G.

Fugitive Emission Sources

The fugitive emission sources at the FMC plant were identified and discussed in Chapter 3. Fugitive dust emissions from plant roads are controlled primarily by using a water truck and adding $MgCl_2$ to the roads.

4.3.1.2 Costs

The costs for the emission control techniques and equipment used by the FMC plant are based on data furnished by the company and adjusted to 1983 dollars. Table 4-12 summarizes the capital, operating, and maintenance costs for the specific major emission source areas. The individual system capital costs, the total operating and maintenance costs, and the costs of the Andersen-2000 units were provided by FMC. All other individual costs were developed on the basis of methodology presented in Ref. [6] and adjusted to 1983 dollars.

Table 4-12. FMC Estimated Airborne Emission Control Equipment Costs in 1983 Dollars.

Emission Source	Control Equipment	Auxiliary Equipment	Capital(1,2) Cost	Annual(2) Operating Cost	Annual(2) Maintenance Cost
Enclosed shale crushing operation and covered conveying system	Standard Havens pulse filters (three)	Hoods, fans stacks	1,186,600	63,800	57,800
#1 calciner and cooler	Parallel disc-slinger wet scrubbers (two), baffled settling chambers (two)	Fans, scrubber pumps, stacks	1,003,600	54,000	48,900
#2 calciner and cooler	Parallel disc-slinger wet scrubbers (two), baffled settling chambers (two)	Fans, scrubber pumps, stacks	1,134,300	61,000	55,400
Nodule stockpile	Standard Havens pulse filter	Hoods, fan, stack	706,500	38,000	34,000
Nodule reclaim	Dustex pulse-reverse air filters (two)	Hoods, fans, stacks	1,378,000	74,000	67,200
Proportioning building	Mikropul pulse filters (two)	Hoods, fans, stacks	1,053,000	56,600	51,300
Coke handling	Mikropul pulse filter	Hoods, fan, stacks	471,200	25,300	23,000
#1 furnace slag and metal tapping operations	Medusa venturi scrubbers (two), Andersen-2000 filter scrubber	Hoods, fan, stack, pump	1,576,500	84,800	76,800
#2 furnace slag and metal tapping operations	Medusa venturi scrubbers (two), Andersen-2000 filter scrubber	Hoods, fan, stack pump	1,576,500	84,800	76,800
#3 furnace slag and metal tapping operations	Medusa venturi scrubbers (two), Andersen-2000 filter scrubber	Hoods, fan stack pump	1,576,500	84,800	76,800
#4 furnace slag and metal tapping operations	Medusa venturi scrubbers (two), Andersen-2000 filter scrubber	Hoods, fan stack, pump	1,576,500	84,800	76,800

Table 4-12. FMC Estimated Airborne Emission Control Equipment Costs in 1983 Dollars. (Continued)

Emission Source	Control Equipment	Auxiliary Equipment	Capital$^{(1,2)}$ Cost	Annual$^{(2)}$ Operating Cost	Annual$^{(2)}$ Maintenance Cost
Phosphorus loading dock	Andersen-2000 filter scrubber	Hoods, fan stack	919,100	49,400	44,800
Slurry drying	2-stage ESP, Medusa venturi scrubber	Fan, stack, pump	3,544,000	190,600	172,700
Burden area above #1 and #2 furnace	BAHCO cassette/pulse filter	Fan, stack	2,686,000	143,000	131,000
Burden area above #3 and #4 furnace	BAHCO cassette/pulse filter	Fan, stack	2,743,500	146,000	133,700
Silo baghouse	Mikropul pulse filter	Fan, stack	668,200	36,000	32,600
Plant roads	Water truck			30,000	
		Plant totals	23,800,000	1,307,000	1,160,000

(1) Capital costs adjusted to 1983 dollars based on Chemical Engineering Plant Cost Index [5].

(2) Developed using the methodology presented in Ref. [6] and adjusted to 1983 dollars.

4.3.2 Stauffer Chemical Plant - Silver Bow, Montana

4.3.2.1 Techniques and Equipment

Point sources of airborne emissions from the Stauffer Chemical-Montana plant were identified in Table 3-13 together with a general listing of the associated emission control equipment. Additional technical information is summarized in Table 4-13 for the major emission control systems. The Stauffer Chemical-Montana plant operates with a state permit regulating operation according to the "State of Montana Air Quality Rules" of the Montana Department of Health and Environmental Sciences - Air Quality Bureau. Point sources of airborne emissions required to comply with applicable limitations and standards are monitored for compliance by visual opacity readings. Stack testing is performed periodically to measure fluoride emissions.

Ore Handling and Rotary Kiln Systems

Ore railcars arriving at the plant are emptied into a pit from which hooded conveyer belts transfer the ore to either of two large stockpiles. The ore is blended before and during transfer by front-end loader to a transfer pit where hooded belt conveyers move it to the kiln feed hoppers. The kiln feed hoppers include fines recycle feed hoppers and provide blended feed ore and recycle dust to two rotary kilns by hooded belt conveyer feeders. Offgas from the hooded ore handling system and material transfer points is vented to a Turbulaire Type D wet scrubber. (See Appendix B for detailed technical information). Particulate removal efficiency for this scrubber is approximately 98 percent.

Kiln offgas is vented into kiln-specific and identical offgas treatment processes consisting of a Buell Multiclone (six cyclones) followed by a redwood spray tower scrubber and a Fluid Ionic Hydro-Precipitrol wet electrostatic precipitator. (See Appendix B for detailed technical informaetion). The spray towers use a lime scrubbing liquor to remove fluorine, P_2O_5, and particulates. Particulate removal efficiencies are approximately 97 percent for the spray towers and 99 percent for the wet electrostatic precipitators. Detailed design data for the ore handling and kiln offgas scrubbers are summarized in Table 4-14.

Table 4-13. Stauffer Chemical-Montana Airborne Emission Control Techniques and Equipment(1).

Emission Point	Emission Source	Type of Equipment	Maintenance(2)	Scrubbing Media
Ore handling system	Ore handling and transfer operations	Turbulaire Type D wet scrubbers	N/A	Recycled process water treated with lime
#1 kiln offgas scrubbers	#1 kiln offgas	Custom-fabricated redwood spray tower	N/A	Recycled process water treated with lime
		Fluid Ionic Hydro-Preciptrol wet ESP	N/A	Recycled process water
#1 kiln nodule cooler scrubber	#1 kiln nodule cooling operation	Turbulaire Type D wet scrubber	N/A	Recycled process water treated with lime
#1 kiln nodule ventilator scrubber	Kiln building operations	Turbulaire Type D wet scrubber	N/A	Recycled process water treated with lime
#2 kiln offgas scrubbers	#2 kiln offgas	Custom-fabricated redwood spray tower	N/A	Recycled process water treated with lime
		Fluid Ionic Hydro-Preciptrol wet ESP	N/A	Recycled process water
#2 kiln nodule cooler scrubber	#2 kiln nodule cooling operation	Turbulaire Type D wet scrubber	N/A	Recycled process water treated with lime
#2 kiln nodule ventilator scrubber	Kiln building operations	Turbulaire Type D wet scrubber	N/A	Recycled process water treated with lime
Feed proportioning silo scrubber	Feed material handling and transfer	Turbulaire Type D wet scrubber	N/A	Recycled process water

Table 4-13. Stauffer Chemical-Montana Airborne Emission Control Techniques and Equipment(1). (Continued)

Emission Point	Emission Source	Type of Equipment	Maintenance(2)	Scrubbing Media
Furnace taphole fume scrubbers	Slag and ferrophosphorus tapping operations	Fluid Ionic Hydro-Preciptrol wet ESP (one)	N/A	Recycled process water
		Custom-fabricated wet venturi scrubber (standby)	N/A	Recycled process water
#1 and #2 furnace offgas condensers (each)	Furnace offgas condensing	Custom-fabricated spray condenser	N/A	Recycled process water
		Clermont wet scrubber	N/A	Recycled process water
Roaster offgas scrubber	Nodule fines and P_4 sludge roasting	Clermont wet scrubber	N/A	Recycled process water

(1) Information obtained from Montana Department of Health and Environmental Sciences - Air Quality Bureau.

(2) Preventive maintenance information not available (N/A). Corrective maintenance assumed upon periodic inspection or as needed.

Table 4-14. Stauffer Chemical-Montana Ore Handling and Kiln Offgas Scrubbers(1).

Emission Point	Mfr. & Model No.	Gas Flow ACMM (ACFM)	Efficiency (%)	Water Rate(2) l/s (gpm)	ΔP(2) cm (in) W.G.
Ore handling system	Western Precipitation Type D Turbulaire wet scrubber	1133 (40,000)	98	N/A	N/A
#1 kiln offgas scrubbers	Custom-fabricated redwood spray tower	991 (35,000)	97.2	N/A	N/A
	Fluid Ionic Hydro-Precipitrol wet ESP	991 (35,000)	99	N/A	2.5-5 (1-2)
#2 kiln offgas scrubbers	Custom-fabricated redwood spray tower	991 (35,000)	97.2	N/A	N/A
	Fluid Ionic Hydro-Precipitrol wet ESP	991 (35,000)	99	N/A	2.5-5 (1-2)

(1) Information obtained from Montana Department of Health and Environmental Sciences - Air Quality Bureau.

(2) Information not available (N/A).

Nodule Cooling and Sizing and Coke Drying Systems

The hot nodules leaving the kilns are passed through kiln-specific processing sequences of nodule cooling, crushing, and screening. The appropriately sized nodular material is sent to storage, and most of the nodule fines are recycled through the kilns. A small quantity of the fines is processed in a phosphorus sludge roaster. The offgas stream from each nodule cooler is treated by a kiln-specific Buell Multiclone followed by a Turbulaire Type D wet scrubber. Particulate removal efficiencies for these scrubbers are approximately 98 percent.

Cooled nodules from the kilns are sent to crushing and screening operations where oversize material is separated out. The nodular material is further screened to separate out fine material, which is sent to the nodule fines roaster. Appropriately sized nodular material is stored before being transferred to the feed proportioning area. Dust from the crushing, sizing, and transfer operations is controlled by the #1 and #2 kiln nodular ventilator scrubbers. The scrubbers are Turbulaire Type D wet scrubbers and operate at approximately 98 percent efficency for particulate removal. Offgas from the coke dryer used to dry coke sent to the feed proportioning area is also controlled by these scrubbers. Detailed design data for the nodule cooling and sizing and coke drying emission control equipment are summarized in Table 4-15.

Feed Proportioning and Burdening Areas

Following sizing, the nodules are sent to the feed proportioning area by hooded belt conveyer where they are stored in silos. Coke and silica sent to the feed proportioning area are stored in separate silos. Emissions from material transfer operations at the top and bottom of the silos are controlled by a Turbulaire Type D wet scrubber with a particulate removal efficiency of approximately 98 percent. Design gas flow rate for this scrubber is 566 ACMM (20,000 ACFM). Additional design data are not available.

Nodules, coke, and silica are mixed using a proportioning weighing system and moved by hooded conveyer to a skip hoist that loads the material into elevated burden bins. The enclosed and pressurized burden bins are located above the two furnaces and continuously feed the furnaces by gravity. No airborne emission control equipment is used at the burden bins.

Table 4-15. Stauffer Chemical-Montana Nodule Cooler and Ventilator Scrubbers(1).

Emission Point	Mfr. & Model No.	Gas Flow ACMM (ACFM)	Efficiency (%)	Water Rate l/s (gpm)	ΔP cm (in) W.G.
#1 kiln nodule cooler scrubber	Western Precipitation Turbulaire Type D wet scrubber	1416 (50,000)	98	N/A	N/A
#2 kiln nodule cooler scrubber	Western Precipitation Turbulaire Type D wet scrubber	1416 (50,000)	98	N/A	N/A
#1 kiln nodule ventilator scrubber	Western Precipitation Turbulaire Type D wet scrubber	1700 (60,000)	98	N/A	N/A
#2 kiln nodule ventilator scrubber	Western Precipitation Turbulaire Type D wet scrubber	1700 (60,000)	98	N/A	N/A

(1) Information obtained from Montana Department of Health and Environmental Sciences - Air Quality Bureau.

(2) Information not available (N/A).

Furnace Taphole Fume and Offgas Filtration Systems

During furnace tapping operations, fumes containing particulates and fluorides are captured by hooded vent systems installed over the furnace tapholes. The vent gases pass through a Fluid Ionic Hydro-Precipitrol wet electrostatic precipitator before discharge to the atmosphere. One scrubber vents both furnaces on alternate cycles. Particulate removal efficiency for this system is approximately 80 percent. A standby wet venturi scrubber is also available but is not normally used.

The offgases from each furnace are drawn through an electrostatic precipitator (one per furnace) where particulates are removed. The cleaned gases are then sent through a condenser (one per furnace) where the gases are cooled and the phosphorus condenses. Offgas from the condensers is routed back to the kilns. Phosphorus condensed in the condensers is collected and filtered before being pumped to storage. Fumes from the condensers and phosphorus handling areas are collected by a single Clermont scrubber containing aerosol candle filters. This scrubber operates with a particulate removal efficiency of approximately 99 percent. Detailed design data for the furnace taphole fume and offgas filtration scrubbers are summarized in Table 4-16.

Fugitive Emission Sources

The fugitive emission sources at the Stauffer Chemical-Montana plant were identified and discussed in Chapter 3. Fugitive dust emissions from roadways are controlled by using a wet, mechanical street sweeper and a water truck.

4.3.2.2 Costs

The costs for the emission control techniques and equipment used by the Stauffer Chemical-Montana plant are based on data furnished by the company. Table 4-17 summarizes the capital, operating, and maintenance costs for the specific major emission source areas. Total capital costs were provided by Stauffer Chemical. All other individual costs were developed on the basis of methodology presented in Ref. [6] and adjusted to 1983 dollars.

Table 4-16. Stauffer Chemical-Montana Furnace and Offgas Filtration Scrubbers(1).

Emission Point	Mfr. & Model No.	Gas Flow ACMM (ACFM)	Efficiency (%)	Water Rate(2) l/s (gpm)	ΔP cm (in) W.G.
Furnace taphole fume scrubber	Fluid Ionic Hydro-Precipitrol wet ESP	1133 (40,000)	80	N/A	2.5-5 (1-2)
	Custom-fabricated wet venturi scrubber (standby)	1133 (40,000)	N/A	N/A	N/A
Furnace offgas condensers (each)	Custom-fabricated spray tower	708 (25,000)	N/A	N/A	N/A
Phosphorus handling system scrubber	Clermont wet scrubber	113 (4000)	99	N/A	11 (4.5)

(1) Information obtained from Montana Department of Health and Environmental Sciences - Air Quality Bureau.

(2) Information not available (N/A).

Table 4-17. Stauffer Chemical-Montana Estimated Airborne Emission Control Equipment Costs in 1983 Dollars.

Emission Source	Control Equipment	Auxiliary Equipment	Capital$^{(1,2)}$ Cost	Annual$^{(2)}$ Operating Cost	Annual$^{(2)}$ Maintenance Cost
Enclosed ore handling system	Turbulaire wet scrubber	Hoods, fan, pump, stack	166,000	10,000	8,300
#1 rotary kiln, #1 nodule cooler and nodule sizing system	Buell multicyclone, spray tower, Fluid Ionic Hydro-Precipitrol wet ESP, recycle cyclone, cooler cyclone, Turbulaire scrubber	Fans, pumps, stacks	2,814,200	168,900	140,700
#2 rotary kiln, #2 nodule cooler and nodule sizing system	Buell multicyclone, spray tower, Fluid Ionic Hydro-Precipitrol wet ESP, recycle cyclone, cooler cyclone, Turbulaire scrubber	Fans, pumps, stacks	2,814,200	168,900	140,700
Proportioning building silo material handling	Turbulaire wet scrubber	Ducts, stack, fan	151,600	9,100	7,600
#1 and #2 kiln nodule ventilators	Buell multicyclones (two), Turbulaire wet scrubbers (two)	Fans, pumps, stacks	533,800	32,000	26,700
#1 and #2 electric furnace condensers offgas	Dry ESP (two), water spray condensers (two)	Fans, pumps, stacks	1,592,800	95,600	83,000
#1 and #2 electric furnaces slag and metal tapping	Fluid Ionic Hydro-Precipitrol wet ESP	Fan, pump, stack	2,599,400	156,000	130,000
Phosphorus sludge roaster	Clermont wet scrubber	Fan, pump, stack	137,900	8,300	6,900
Plant Roads	Water truck			30,000	
		Plant Total	10,809,900	678,800	543,900

(1) Capital costs adjusted to 1983 dollars based on the Chemical Engineering Plant Cost Indix [5].

(2) Developed using the methodology presented in Ref. [6] and adjusted to 1983 collars.

4.3.3 Stauffer Chemical Plant - Mt. Pleasant, Tennessee

4.3.3.1 Techniques and Equipment

Point sources of airborne emissions from the Stauffer Chemical-Tennessee plant were identified in Table 3-18 together with a general listing of the associated emission control techniques and equipment. Additional technical information is summarized in Table 4-18 for the major emission control systems. The Stauffer Chemical-Tennessee plant operates with a state permit limiting particulate emissions according to Chapter 1200 of "Rules of Tennessee Department of Public Health" - Bureau of Environmental Health Services - Division of Air Pollution Control. Point sources of airborne emissions required to comply with applicable limitations and standards are monitored for compliance by visual opacity readings. Although not required, stack emissions are tested annually.

Ore Handling and Rotary Kiln Systems

Ore trucks arriving at the plant are emptied into a pit from which hooded conveyer belts transfer the ore to one of two large stockpiles. The ore is blended before and during transfer by front-end loader to a transfer pit where hooded belt conveyers move it to the kiln feed hoppers. The kiln feed hoppers include fines recycle feed hoppers and provide blended feed ore and recycle dust to two rotary kilns by hooded belt conveyer. The entire ore handling process meets airborne emission standards without the use of emission control equipment.

Kiln offgas is vented into kiln-specific and identical offgas treatment processes consisting of a Buell Multiclone (six cyclones) followed by a custom-fabricated water spray scrubbing tower. Only the larger (#2 kiln) of the two kilns is currently used and is anticipated being used in the foreseeable future. The wet scrubbers use a lime scrubbing liquor to remove fluorine, SO_2, and particulates. The scrubbers are each designed with an inverted cone upper section that expands into a larger diameter stack. A lime storage silo stores lime used in a clarifier that provides the scrubbers with water. The lime storage silo is vented to a baghouse dust collector for particulate control. Particulate removal efficiency for the kiln scrubbers is approximately 99.8 percent and for the lime storage

Table 4-18. Stauffer Chemical-Tennessee Airborne Emission Control Techniques and Equipment(1).

Emission Point	Emission Source	Type of Equipment	Maintenance(2)	Dust Disposal	Scrubbing Media
#1 kiln scrubber (inactive)	#1 kiln offgas	Custom-fabricated spray tower	N/A	-	Recycled process water treated with lime
#2 kiln scrubber	#2 kiln offgas	Custom-fabricated spray tower	N/A	-	Recycled process water treated with lime
Lime storage silo baghouse	Lime handling operation	Baghouse filter (type N/A)	N/A	Recycled back to process	-
#1 kiln cooler scrubber	Nodule cooling operation	Custom-fabricated spray tower	N/A	-	Recycled process water treated with lime
#2 kiln cooler scrubber (inactive)	Nodule cooling operation	Custom-fabricated spray tower	N/A	-	Recycled process water treated with lime
#2 kiln nodule crush/screen scrubber	Nodule crushing and screening operation	Custom-fabricated spray tower	N/A	-	Recycled process water
#2 kiln nodule fines screen scrubber	Nodule screening operation	Turbulaire Type D wet scrubber	N/A	-	Recycled process water
#2 kiln nodule fines handling scrubber	Nodule fines handling operation	Turbulaire Type D wet scrubber	N/A	-	Recycled process water
Nodule transfer house scrubber	Nodule transfer operation	Turbulaire Type D wet scrubber	N/A	-	Recycled process water
Coke dryer scrubber (inactive)	Coke drying operation	Turbulaire Type D wet scrubber	N/A	-	Recycled process water
Feed storage silo scrubber	Feed material handling and transfer	Turbulaire Type D wet scrubber	N/A	-	Recycled process water
Skip hoist scrubber	Feed material handling and transfer	Turbulaire Type D wet scrubber	N/A	-	Recycled process water

Table 4-18. Stauffer Chemical-Tennessee Airborne Emission Control Techniques and Equipment(1). (Continued)

Emission Point	Emission Source	Type of Equipment	Maintenance(2)	Dust Disposal	Scrubbing Media
#2, 3, 4 furnace building burdening scrubber	Burdening material handling and transfer	Turbulaire Type D wet scrubber	N/A	-	Recycled process water
#5 furnace building scrubber	Burdening material handling and transfer	Turbulaire Type D wet scrubber	N/A	-	Recycled process water
#2 furnace taphole fume scrubber	Slag and ferrophosphorus tapping operations	Custom-fabricated wet venturi scrubber	N/A	-	Recycled process water
#3 and #4 furnace taphole fume scrubber	Slag and ferrophosphorus tapping operations	Custom-fabricated wet venturi scrubber	N/A	-	Recycled process water
#5 furnace taphole fume scrubber	Slag and ferrophosphorus tapping operations	Custom-fabricated wet venturi scrubber	N/A	-	Recycled process water
Furnace condenser spray towers (four)	Furnace offgas condensing	Custom-fabricated spray towers	N/A	-	Recycled process water
#1 Roaster condenser	Nodule fines and P_4 sludge roasting	Custom-fabricated water spray condensers	N/A	-	Recycled process water
#2 Roaster condenser	Nodule fines and P_4 sludge roasting	Custom-fabricated water spray condensers	N/A	-	Recycled process water

(1) Information obtained from Tennessee Department of Public Health - Bureau of Environmental Health Services and from data presented to SAI staff at November 9, 1982, meeting at Stauffer Chemical plant in Mt. Pleasant, Tennessee.

(2) Preventive maintenance information not available (N/A). Corrective maintenance assumed upon periodic inspection or as needed.

silo baghouse is greater than 99 percent. Detailed design data for the kiln scrubbers and lime storage silo baghouse are summarized in Table 4-19.

Nodule Cooling and Sizing Systems

The hot nodules leaving the kilns are passed through kiln-specific processing sequences of nodule cooling, crushing, and screening. The appropriately sized nodular material is sent to nodule storage and the nodule fines are sent to the nodule fines roasters. The offgas stream from the #1 kiln nodule cooler is mixed with the nodule crushing and sizing offgas stream and is treated by a spray tower scrubber. Particulate removal efficiency for the #1 kiln cooler scrubber is approximately 99 percent.

The offgas stream from the #2 kiln nodule cooler is treated by a spray tower scrubber operating at approximately 99 percent efficiency. Cooled nodules from the #2 kiln are sent to a crushing and screening operation where oversize material is separated out. Offgas from this operation is vented to a water spray tower scrubber that removes particulates at approximately 98.8 percent efficiency. The nodular material is further screened to separate out fine material. Fines are sent to storage and loading before transfer to the fines and phosphorus sludge roasters. Appropriately sized nodular material is sent to the nodule transfer house before being transferred to nodule storage silos. Offgases from the screening, fines handling and transfer, and nodule transfer house operations are collected by three Turbulaire wet scrubbers. Efficiencies for particulate removal range from 98.6 to 99.4 percent for these scrubbers. Detailed design data for the nodule cooling and sizing scrubbers are summarized in Table 4-20.

Feed Proportioning and Burdening Areas

Following sizing, the nodules are sent to the proportioning area and stored in silos. Coke sent to the proportioning area may first be dried in the coke dryer. However, the coke dryer is not currently used. When in use, offgas from the coke dryer is treated for dust removal by a Turbulaire wet scrubber. Efficiency of the scrubber for particulate removal is approximately 97 percent. The coke, silica, and nodules sent to the feed proportioning area are stored in separate silos. Material transfer

Table 4-19. Stauffer Chemical-Tennessee Kiln Airborne Emission Control Equipment(1).

Emission Point	Mfr. & Model No.	Gas Flow ACMM (ACFM)	Efficiency (%)	Water Rate l/s (gpm)	Air to Cloth Ratio	ΔP cm (in) W.G.
#1 kiln offgas scrubber	Custom-fabricated Stauffer Chemical design	1561 (55,000)	99.8	50 (800)	-	N/A(3)
#2 kiln offgas scrubber	Custom-fabricated Stauffer Chemical design	3538 (125,000)	99.8	70 (1120)	-	N/A
Lime storage silo baghouse	N/A	15 (500)	99+	-	N/A	N/A

(1) Information obtained from Tennessee Department of Public Health - Bureau of Environmental Health Services.

(2) Data presented to SAI staff at November 9, 1982, meeting at Stauffer Chemical plant in Mt. Pleasant, Tennessee.

(3) Information not available (N/A).

Table 4-20. Stauffer Chemical-Tennessee Nodule Cooling and Sizing Scrubbers(1).

Emission Point	Mfr. & Model No.	Gas Flow ACMM (ACFM)	Efficiency (%)	Water Rate(2) l/s (gpm)	ΔP cm (in) W.G.
#1 kiln cooler scrubber	Custom-fabricated Stauffer Chemical design	1558 (55,000)	99	N/A(3)	N/A
#2 kiln cooler scrubber	Custom-fabricated Stauffer Chemical design	3455 (122,000)	99	12 (190)	9 (3.5)
#2 kiln nodule crush/screen scrubber	Custom-fabricated Stauffer Chemical design	1614 (57,000)	98.8	3.8 (60)	13 (5.0)
#2 kiln nodule fines scrubber	Western Precipitation Type D Turbulaire wet scrubber	353 (12,500)	99.4	1.9 (30)	22 (8.8)
#2 kiln nodule fines handling scrubber	Western Precipitation Type D Turbulaire wet scrubber	127 (4500)	99.6	1.3 (20)	4 (1.5)
Nodule transfer house scrubber	Western Precipitation Type D Turbulaire wet scrubber	380 (13,500)	98.6	1.3 (20)	9 (3.5)

(1) Information obtained from Tennessee Department of Public Health - Bureau of Environmental Health Services.

(2) Data presented to SAI staff at November 9, 1982, meeting at Stauffer Chemical plant in Mt. Pleasant, Tennessee.

(3) Information not available (N/A).

operations at the top and bottom of the silos are controlled by a Turbulaire wet scrubber with a particulate removal efficiency of approximately 93 percent.

The furnace burden material is moved by a hooded belt conveyer to a skip hoist that transfers the material into elevated burden bins in the furnace building proportioning areas. Dust from the skip hoist operations is controlled by a Turbulaire wet scrubber with a particulate removal efficiency of approximately 91 percent. The enclosed burden bins are located above the furnaces and continuously feed the furnaces by gravity. Offgas vented from burden bins associated with three (#2, 3, 4) of the four operating furnaces is treated by a Turbulaire wet scrubber. Offgas vented from the burden bin feeding the other furnace (#5) is treated by another Turbulaire wet scrubber. Particulate removal efficiences for these scrubbers are approximately 97-99 percent. Detailed design data for the feed proportioning and burdening areas are summarized in Table 4-21.

Furnace Taphole Fume and Offgas Filtration Systems

During furnace tapping operations, fumes containing particulates and fluorides are captured by hooded vent systems installed over the tapholes of the furnaces. The vent gases pass through a custom-fabricated venturi scrubber and into a cyclonic separator before discharge to the atmosphere. Only three such systems are used because the taphole fumes from #3 and #4 furnaces are treated in one emission control system. Particulate removal efficiencies for these systems range from approximately 92 to 97 percent.

The offgases from each furnace are condensed in water spray condenser systems. Sludge resulting from filtration of condensed phosphorus is sent to one of two roasters along with nodule fines from the nodule sizing operation. Offgas from each roaster is sent to a water spray condenser where phosphorus is condensed and particulates are removed. Detailed design data for the furnace taphole fume and offgas filtration system scrubbers are summarized in Table 4-22.

Table 4-21. Stauffer Chemical-Tennessee Feed Proportioning and Burdening Scrubbers(1).

Emission Point	Mfr. & Model No.	Gas Flow ACMM (ACFM)	Efficiency (%)	Water Rate(2) l/s (gpm)	ΔP(2) cm (in) W.G.
Coke dryer scrubber	Western Precipitation Type D Turbulaire wet scrubber	1133 (40,000)	97	6.6 (105)	13 (5.0)
Feed storage silo scrubber	Western Precipitation Type D Turbulaire wet scrubber	906 (32,000)	93	3.1 (50)	15 (6.0)
Skip hoist scrubber	Western Precipitation Type D Turbulaire wet scrubber	566 (20,000)	91	3.1 (50)	18 (7.5)
#2, 3, 4 furnace building burdening scrubber	Western Precipitation Type D Turbulaire wet scrubber	198 (7000)	98.9	1.9 (30)	18 (7.5)
#5 furnace building burdening scrubber	Western Precipitation Type D Turbulaire wet scrubber	113 (4000)	97	1.3 (20)	7.5 (3.0)

(1) Information obtained from Tennessee Department of Public Health - Bureau of Environmental Health Services.

(2) Data presented to SAI staff at November 9, 1982, meeting at Stauffer Chemical plant in Mt. Pleasant, Tennessee.

Table 4-22. Stauffer Chemical-Tennessee Furnace and Offgas Filtration System Scrubbers(1).

Emission Point	Mfr. & Model No.	Gas Flow ACMM (ACFM)	Efficiency (%)	Water Rate l/s (gpm)	ΔP(2) cm (in) W.G.
#2 furnace taphole fume scrubber	Custom-fabricated wet venturi scrubber	765 (27,000)	96	N/A	94 (37)
#3 and #4 furnace taphole fume scrubber	Custom-fabricated wet venturi scrubber	765 (27,000)	92	N/A	94 (37)
#5 furnace taphole fume scrubber	Custom-fabricated wet venturi scrubber	765 (27,000)	97	N/A	81 (32)
Furnace condenser spray towers (four)	Custom-fabricated spray towers	N/A(3)	N/A	N/A	N/A
#1 roaster condenser	Custom-fabricated water spray condenser	1.1 (40)	N/A	N/A	N/A
#3 roaster condenser	Custom-fabricated water spray condenser	1.1 (40)	N/A	N/A	N/A

(1) Information obtained from Tennessee Department of Public Health - Bureau of Environmental Health Services.

(2) Data presented to SAI staff at November 9, 1982, meeting at Stauffer Chemical plant in Mt. Pleasant, Tennessee.

(3) Information not available (N/A).

Fugitive Emission Sources

The fugitive emission sources at the Stauffer Chemical-Tennessee plant were identified and discussed in Chapter 3. Fugitive dust emissions from roadways are controlled through the use of a mechanical street sweeper.

4.3.3.2 Costs

The costs for the emission control techniques and equipment used by the Stauffer Chemical-Tennessee plant are based on data furnished by the company. Table 4-23 summarizes the capital, operating, and maintenance costs for the specific major emission source areas. Total capital costs were provided by Stauffer Chemical [9]. All other individual costs were developed on the basis of methodology presented in Ref. [6] and adjusted to 1983 dollars.

Table 4-23. Stauffer Chemical-Tennessee Estimated Airborne Emission Control Equipment Costs in 1983 Dollars.

Emission Source	Control Equipment	Auxiliary Equipment	Capital$^{(1,2)}$ Cost	Annual$^{(2)}$ Operating Cost	Annual$^{(2)}$ Maintenance Cost
#1 rotary kiln, #1 nodule cooler and nodule sizing system (inactive)	Buell Multiclone and kiln spray tower, Buell Multiclone and cooler spray tower	Kiln stack, fan and pumps, cooler stack, fans and pumps	1,133,200	158,900	62,200
#2 rotary kiln, #2 nodule cooler and nodule sizing system	Buell Multiclone and kiln spray tower, Buell Multiclone and cooler spray tower, crusher/screen spray tower, nodule transfer screen Turbulaire scrubber	Fans, pumps, stacks	2,122,000	297,600	116,500
Lime storage silo	Baghouse filter	Fan, stack	76,600	10,700	4,200
Nodule transfer house	Turbulaire scrubber	Fan, pump, stack	171,700	24,000	9,400
Proportioning building	Turbulaire scrubbers (two)	Fans, pumps, stacks	310,800	43,600	17,000
Feed storage silos	Turbulaire scrubber	Fan, pump, stack	234,500	32,900	12,900
Coke drying, sizing and handling	Turbulaire scrubber	Fan, pump, stack	297,800	41,800	16,300
Skip hoist system	Turbulaire scrubber	Fan, pump, stack	234,500	32,900	12,900
Electric furnaces offgas condensers (four)	Water spray condensers (four)	Filters, pumps, fans, stacks	1,542,500	117,300	46,000

Table 4-23. Stauffer Chemical-Tennessee Estimated Airborne Emission Control Equipment Costs in 1983 Dollars. (Continued)

Emission Source	Control Equipment	Auxiliary Equipment	Capital(1,2) Cost	Annual(2) Operating Cost	Annual(2) Maintenance Cost
Electric furnaces slag and ferro-phosphorus tapping	Venturi scrubbers (three), cyclone separators (three)	Pumps, tanks, fans, stacks	960,200	134,700	52,700
Roaster offgas condensers	Water spray condensers (two)	Fans, pumps, stacks	81,300	11,400	4,500
		Plant Totals	7,165,100	905,800	354,600

(1) Capital costs adjusted to 1983 dollars based on the Chemical Engineering Plant Cost Index [5].

(2) Developed using the methodology presented in Ref. [6] and adjusted to 1983 dollars.

4.3.4 Stauffer Chemical Plant - Tarpon Springs, Florida

4.3.4.1 Techniques and Equipment

Point sources of airborne emissions from the Stauffer Chemical-Florida plant were identified in Table 3-23 together with a general listing of the associated emission control techniques and equipment. Additional technical information is summarized in Table 4-24 for the major emission control systems. When operating, the Stauffer Chemical-Florida plant operates with a state permit limiting particulate emissions according to Chapters 17-2 and 17-4 of the Florida Administrative Code - Rules of the Florida Department of Environmental Regulation. Point sources of airborne emissions required to comply with applicable limitations and standards are monitored for compliance by annual stack testing and visual opacity readings. In some instances, sources are tested semiannually.

Ore Handling and Rotary Kiln Systems

Ore railcars arriving at the plant are emptied into a pit from which hooded conveyer belts transfer the ore to a feed bin. Kiln feed hoppers include a fines recycle feed hopper for coke dust, nodule dust, and ore transfer dust. They provide blended feed ore and recycle dust to the kiln feeder lift elevator by a hooded belt conveyer. Fugitive dust from these material handling operations is collected by two American Air Filter (AAF) Amerpulse bag collectors. When the plant resumes operation, the kiln feed collector will be replaced with an AAF rotoclone. The rotary kiln offgas is vented into a treatment system consisting of eight Buell cyclones followed by a custom-fabricated redwood spray scrubbing tower with an inverted cone upper section leading to a small diameter stack. The wet scrubber uses a lime scrubbing liquor to remove fluorine, P_2O_5, and particulates. Efficiency for particulate removal is approximately 99 percent. Detailed design data for these baghouses are summarized in Table 4-25.

Nodule Cooling and Sizing Systems

Hot nodules leaving the kiln are sequentially cooled , crushed and screened. The offgas from the oscillating undergrate cooler is treated sequentially by a saturation pre-scrub cooler followed by a Turbulaire Type D wet scrubber and cyclone separator. Air from dust hoods venting the

Table 4-24. Stauffer Chemical-Florida Airborne Emission Control Techniques and Equipment[1].

Emission Point	Emission Source	Type of Equipment	Maintenance(2)	Dust Disposal	Scrubbing Media
Ore handling baghouses (two)	Ore handling and transfer operations	AAF Amerpulse bag collectors(3)	N/A	Recycled to kiln recycle feed bin	-
Kiln scrubber	Kiln offgas	Custom-fabricated redwood spray tower	N/A	-	Recycled process water treated with lime
Nodule cooler scrubber	Nodule cooling operation	Turbulaire Type D scrubber	N/A	-	Recycled process water treated with lime
Nodule crushing and sizing system scrubber	Nodule crushing and screening operations	AAF Type R Rotoclone wet centrifugal collector	N/A	-	Recycled process water
Feed proportioning area silo bag collectors (two)	Feed proportioning area material handling and transfer	AAF Fabri-Pulse bag collectors	N/A	Recycled to kiln recycle feed bin	-
Burdening area scrubber	Burdening area material handling and transfer	AAF Type R Rotoclone wet centrifugal collector	N/A	-	Recycled process water
Furnace taphole fume scrubber	Slag and ferrophosphorus tapping operations	Wet venturi scrubber	N/A	-	Recycled process water
Furnace offgas condenser	Furnace offgas CO	Lane condenser	N/A	-	Recycled process water
Phosphorus handling area	Area fumes	Clermont mist eliminator tower	N/A	-	Aerosol candle filters
Roaster condenser	Nodule fines and P_4 sludge roasting	Custom-fabricated water spray condenser	N/A	-	Recycled process water

(1) Information obtained from Florida Department of Environmental Regulation and from data presented to SAI staff at November 9, 1982, meeting at Stauffer Chemical plant in Mt. Pleasant, Tennessee.

(2) Preventive maintenance information not available (N/A). Corrective maintenance assumed upon periodic inspection or as needed.

(3) When the plant resumes operation, one of these units will be replaced by an American Air Filter Rotoclone.

Table 4-25. Stauffer Chemical-Florida Ore Handling and Kiln Offgas Airborne Emission Control Equipment(1).

Emission Point	Mfr. & Model No.	Gas Flow ACMM (ACFM)	Efficiency (%)	Water Rate l/s (gpm)	Air to Cloth Ratio	ΔP cm (in) W.G.
Ore handling baghouse (two)	American Air Filter Amerpulse bag collectors(3)	142 (5000)	99+	-	N/A(2)	N/A
Kiln scrubber	Custom-fabricated redwood spray tower	935 (33,000)	99	100 (1600)	-	N/A

(1) Information obtained from Florida Department of Environmental Regulation.

(2) Information not available (N/A).

(3) When the plant resumes operation, one of these units will be replaced by an American Air Filter Rotoclone.

nodule pan conveyer and transfer to the nodule crusher is also treated by this scrubber. Efficiency for particulate removal is approximately 98.8 percent.

Dust from the crushing and screening operations is vented to an AAF type R Rotoclone wet centrifugal collector. This system operates at an efficiency of 99 percent for particles larger than 10 μm and 90 percent for particles larger than 2 μm. Since most of the the particulates treated are larger than 10 μm, the overall efficiency for the system is approximately 99 percent. Detailed design data for the nodule cooling and sizing system scrubbers are summarized in Table 4-26.

Feed Proportioning and Burdening Areas

Following sizing, the nodules are sent to the proportioning area for storage. Nodules, coke, and silica are mixed using a proportioning weighing system. Coke is sized on site before being sent to the proportioning building. Feed materials sent to the proportioning building are stored in separate silos. Material transfer operations at the top and bottom of the silos are controlled by two AAF Fabric-Pulse pulse-jet fabric dust collectors.

The furnace burden material is moved by a hooded belt conveyer that loads the material into the elevated burden bins. Dust from the enclosed burden bin area is vented and collected by an AAF Type R Rotoclone wet centrifugal collector. This system operates at an efficiency of approximately 95 percent for particulate removal. Detailed design data for the feed proportioning and burdening area emission control equipment are summarized in Table 4-27.

Furnace Taphole Fume and Offgas Filtration Systems

During furnace tapping operations, fumes containing particulates and fluorides are captured by a hooded vent system installed over the tapholes of the furnace. The vent gases pass through a custom-fabricated venturi scrubber and into a cyclonic separator before discharge to the atmosphere. The efficiency of the venturi scrubber for particulate removal is approximately 80 percent.

The furnace offgases are condensed in a Lane condenser before recycle of CO to the kilns. Condensed phosphorus is filtered in the phos-

Table 4-26. Stauffer Chemical-Florida Nodule Cooling and Sizing Scrubbers(1).

Emission Point	Mfr. & Model No.	Gas Flow ACMM (ACFM)	Efficiency (%)	Water Rate l/s (gpm)	ΔP cm (in) W.G.
Nodule cooler scrubbing	Western Precipitation Type D Turbulaire wet scrubber	1982 (70,000)	98.8	N/A(2)	N/A
Nodule crushing and sizing system scrubber	AAF Size 4 Type R Rotoclone wet centrifugal collector	566 (20,000)	99 (+10 μm) 90 (+ 2 μm)	4 (70)(3)	18 (7)(3)

(1) Information obtained from Florida Department of Environmental Regulation.

(2) Information not available (N/A).

(3) Estimated based on vendor literature.

Table 4-27. Stauffer Chemical-Florida Feed Proportioning and Burdening Airborne Emission Control Equipment(1)

Emission Point	Mfr. & Model No.	Gas Flow ACMM (ACFM)	Efficiency (%)	Water Rate l/s (gpm)	Air to Cloth Ratio	ΔP cm (in) W.G.
Feed proportioning area top silo bag collector	AAF Fabri-Pulse bag collector	227 (8000)	N/A(2)	-	N/A	7.5-18 (3-7)(3)
Feed proportioning area bottom silo bag collector	AAF Fabri-Pulse bag collector	736 (26,000)	N/A	-	N/A	7.5-18 (3-7)(3)
Burdening area scrubber	AAF Type R Rotoclone wet centrifugal collector	230 (8100)	95	1.8 (28)(3)	-	12 (5)

(1) Information obtained from Florida Department of Environmental Regulation.

(2) Information not available (N/A).

(3) Estimated based on vendor literature.

phorus handling area. Sludge resulting from the filtration process is sent to a roaster along with nodule fines from the nodule sizing operation. Offgas from the roaster is treated in a water spray condenser that removes particles larger than 10 μm with an efficiency of 90 percent.

Fumes from the Lane condenser and phosphorus handling area are treated by a tower containing two Clermont aerosol candle filters. This vessel operates with a 99.5 percent efficiency for all particulates. Detailed design data for the furnace taphole fume and offgas filtration system scrubbers are summarized in Table 4-28.

Fugitive Emission Sources

The fugitive emission sources at the Stauffer Chemical-Florida plant were identified and discussed in Chapter 3. Fugitive dust emissions from paved plant roads are controlled by using a mechanical street sweeper.

4.3.4.2 Costs

The costs for the emission control techniques and equipment used by the Stauffer Chemical-Florida plant are based on data furnished by the company. Table 4-29 summarizes the capital, operating, and maintenance costs for the specific major emission source areas. Total capital costs were provided by Stauffer Chemical. All other individual costs were developed on the basis of methodology presented in Ref. [6] and adjusted to 1983 dollars.

Table 4-28. Stauffer Chemical-Florida Furnace and Offgas Filtration Scrubbers$^{(1)}$.

Emission Point	Mfr. & Model No.	Gas Flow ACMM (ACFM)	Efficiency (%)	Water Rate l/s (gpm)	ΔP cm (in) W.G.
Furnace taphole fume scrubber	Custom-fabricated venturi scrubber	595 (21,000)	80	N/A$^{(2)}$	N/A
Furnace offgas condenser	Lane condenser	N/A	N/A	N/A	N/A
Phosphorus handling area	Custom-fabricated Clermont mist eliminator tower	43 (1500)	99.5	-	18-25 (7-10)$^{(3)}$
Roaster condenser	Custom-fabricated water spray condenser	N/A	90 (+10 µm)	1.6 (25)	N/A

(1) Information obtained from Florida Department of Environmental Regulation.

(2) Information not available (N/A).

(3) Estimated based on vendor literature.

Table 4-29. Stauffer Chemical-Florida Estimated Airborne Emission Control Equipment Costs in 1983.

Emission Source	Control Equipment	Auxiliary Equipment	Capital(1,2) Cost	Annual(2) Operating Cost	Annual(2) Maintenance Cost
Enclosed ore handling system	American Air Filter Amerpulse bag filters (two)	Hoods, fan, stack	429,400	85,900	34,400
Rotary kiln	Buell Mutliclone, spray tower scrubber	Fan, pump, tanks, stack	244,900	49,000	19,600
Nodule cooler	Saturation pre-scrub cooler, Turbulaire scrubber, cyclonic separator	Fan, pump, stack	1,106,500	221,300	88,500
Nodule sizing system	American Air Filter Rotoclone	Stack	43,300	8,700	3,500
Feed proportioning system	American Air Filter Fabri-Pulse bag filters (two), Rotoclone	Fans, stack	442,200	88,400	35,400
Electric furnace offgas condenser	Lane condenser	Fan, pump, stack	594,000	118,800	47,500
Furnace taphole fume system	Venturi scrubber, cyclone separator	Fan, stack	201,000	40,200	16,000
Phosphorus handling system	Clermont wet scrubber	Fan, pump, stack	90,000	18,000	7,200
Roaster offgas condenser	Spray tower condenser	Fan, pump, stack	194,000	39,000	16,000
		Plant Totals	3,345,300	669,300	268,100

(1) Capital costs adjusted to 1983 dollars based on the Chemical Engineering Plant Cost Index [5].

(2) Developed using the methodology presented in Ref. [6] and adjusted to 1983 dollars.

4.3.5 Monsanto Plant - Columbia, Tennessee

4.3.5.1 Techniques and Equipment

Point sources of airborne emissions from the Monsanto-Tennesse plant were identified in Table 3-28 together with a general listing of the associated emission control techniques and equipment. Additional technical information is summarized in Table 4-30 for the major emission control systems. The Monsanto-Tennessee plant operates with a state permit limiting particulate emissions according to Chapter 1200 of "Rules of Tennessee Department of Public Health" - Bureau of Environmental Health Services - Division of Air Pollution Control. Point sources of airborne emissions required to comply with applicable limitations and standards are monitored for compliance by visual opacity readings. Although not required, stack emissions are tested periodically.

Kiln and Nodule Cooler Systems

Raw ore shipped to the plant is washed in one of two ore spray washing systems. Washed ore is then blended with recycle dust from the kilns and screening plant operations before being fed to the rotary kilns by belt conveyers. Dust wetting emission controls are used with these ore handling processes.

Offgases from the three kilns are vented into kiln-specific sequential treatment operations consisting of a cyclone, spray tower scrubber, and demister stack. Lime is added to the scrubber spray tower to aid in removal of fluorine and SO_2. Entrained water in the exhaust gases is removed in the demister stacks. Waste water from spray tower discharges is recycled through a pond that serves as a settling pond for suspended solids and is used to make lime slurry and spray for the scrubbers. Cyclone particulate removal efficiency is 75 to 85 percent. Spray tower particulate removal efficiency is approximately 99 percent for the #1 and #2 kiln spray towers and 99.5 percent for the #3 kiln spray tower.

The hot nodules from each kiln are passed through a nodule cooler and are conveyed by a series of hooded conveyers to the nodule storage craneway or directly to one of three nodule sizing systems. Offgases from each nodule cooler are vented to a separate jet eductor scrubber for emission control. Particulate removal efficiences for these scrubbers are 99.6

Table 4-30. Monsanto-Tennessee Airborne Emission Control Techniques and Equipment(1).

Emission Point	Emission Source	Type of Equipment	Maintenance(2)	Dust Disposal	Scrubbing Media
#1 kiln offgas scrubber	#1 kiln offgas	Custom-fabricated spray tower	N/A	-	Recycled process water plus lime
#2 kiln offgas scrubber	#2 kiln offgas	Custom-fabricated spray tower	N/A	-	Recycled process water plus lime
#3 kiln offgas scrubber	#3 kiln offgas	Custom-fabricated spray tower	N/A	-	Recycled process water plus lime
#1 kiln nodule cooler scrubber	#1 kiln nodule cooling operation	Custom-fabricated jet eductor scrubber	N/A	-	Recycled porcess water plus lime
#2 kiln nodule cooler scrubber	#2 kiln nodule cooling operation	Custom-fabricated jet eductor scrubber	N/A	-	Recycled process water plus lime
#3 kiln nodule cooler scrubber	#3 kiln nodule cooling operation	Custom-fabricated jet eductor scrubber	N/A	-	Recycled process water plus lime
#1 nodule sizing system scrubber	Nodule crushing and screening operation	American Air Filter Type R Rotoclone	N/A	Dust sent to pond	Raw water
#2 nodule sizing system scrubber	Nodule crushing and screening operation	American Air Filter Type R Rotoclone	N/A	Dust sent to pond	Raw water
#3 nodule sizing system scrubber	Nodule crushing and screening operation	American Air Filter Type R Rotoclone	N/A	Dust sent to pond	Raw water
North scaleroom baghouse	Burden material handling	Lear Siegler/Luhr filter baghouse	N/A	Dust sent to pond	-
South scaleroom baghouse	Burden material handling	Lear Siegler/Luhr filter baghouse	N/A	Dust sent to pond	-
North burden transfer baghouse	Burden material transfer	Lear Siegler/Luhr filter baghouse	N/A	Dust recycled to kiln	-
South burden transfer baghouse	Burden material transfer	American Air Filter bag filter	N/A	Dust recycled to kiln	-

Table 4-30. Monsanto-Tennessee Airborne Emission Control Techniques and Equipment(1). (Cont'd)

Emission Point	Emission Source	Type of Equipment	Maintenance(2)	Dust Disposal	Scrubbing Media
Central furnace stocking baghouse	Burdening material handling and storage	Buell bag collector	N/A	Dust recycled back to process	-
Coke unloading area baghouse	Coke unloading operation	Bag filter	N/A	Dust recycled back to process	-
Coke silo baghouse	Coke storage	Bag filter	N/A	Dust recycled back to process	-
Coke screen baghouse	Coke screening operation	Bag filter	N/A	Dust recycled back to process	-
Coke dryer scrubber	Coke drying operation	Custom-fabricated wet venturi scrubber	N/A	Dust sent back to pond	Raw water
North furnace stocking baghouse	Furnace stocking burden handling	Bag filter	N/A	Dust recycled back to process	-
South furnace stocking baghouse	Furnace stocking burden handling	Bag filter	N/A	Dust recycled back to process	-
#1 through #6 furnace taphole fume scrubbers (each)	Slag and ferrophosphorus tapping operations	Custom-fabricated wet venturi scrubber	N/A	-	Recycled process water
#1 through #6 furnace offgas systems (each)	Furnace offgas condensing and filtration	Custom-fabricated water spray condenser	N/A	-	Recycled process water plus lime
#1 through #6 furnace CO flares (each)		Custom-fabricated wet venturi scrubber	N/A	-	Recycled process water plus lime

(1) Information obtained from Tennessee Department of Public Health - Bureau of Environmental Health Services and Ref. [10].

(2) Preventive maintenance information not available (N/A).

(3) Corrective maintenance assumed upon periodic inspection or as needed.

to 99.7 percent. Detailed design data for kiln and nodule cooler airborne emission control equipment are summarized in Table 4-31.

Nodule Sizing Systems

Three nodule sizing systems are operated at the Monsanto-Tennessee plant. The purpose of the #1 nodule sizing system is to crush, size, convey, and store kiln products directly from the nodule coolers. The #2 nodule sizing system processes nodules from bin storage and includes sizing, conveying, and storing operations, but does not incorporate crushing. The #3 nodule sizing system also processes nodules from storage but includes crushing. Particulate emissions from the nodule sizing systems (approximately 8.8 weight percent of the particles are <15 μm) are controlled by three American Air Filter Type R Size 9 Rotoclones. Particulate removal efficiencies for these systems are approximately 98 percent. Detailed design data for the nodule sizing system scrubbers are summarized in Table 4-32.

Feed Proportioning Area and Coke Handling Systems

Following sizing, the nodular material is stored and transferred by hooded belt conveyer to the feed proportioning building as needed. Coke is dried and sized on site and the sized coke is stored in bins feeding the burden scales. At the burden scales, coke, silica, and nodules are mixed using a proportioning weighing system. The burden is moved by hooded belt conveyer to an intermediate transfer bin that distributes it into one of six furnace feed hoppers. Offgases from operations at the burden scales (approximately 31 weight percent of the particles are <18 μm) are vented to two parallel Lear Siegler/Luhr filter baghouse systems for dust removal. A similar offgas treatment system consisting of Lear Siegler/Luhr filter and American Air Filter baghouse systems is used for the burden transfer system. Particulate removal efficiencies for the scale room and burden transfer baghouses are 99.95 to 99.97 percent. Offgas from the intermediate transfer bin operation (central furnace stocking system) is controlled by a Buell bag dust collector with a particulate removal efficiency of approximately 99.94 percent (approximately 7 weight percent of the particles are <13 μm).

Offgases from the coke handling operations are controlled by three baghouse dust collectors located at the coke unloading area, the coke silo,

Table 4-31. Monsanto-Tennessee Kiln Offgas and Nodule Cooler Scrubbers(1).

Emission Point	Mfr. & Model No.	Gas Flow ACMM (ACFM)	Efficiency (%)	Water Rate(2) l/s (gpm)	ΔP(2) cm (in) W.G.
#1 kiln offgas scrubber	Custom-fabricated spray tower	4450 (157,000)	99	N/A	N/A
#2 kiln offgas scrubber	Custom-fabricated spray tower	4450 (157,000)	99	N/A	N/A
#3 kiln offgas scrubber	Custom-fabricated spray tower	4760 (168,000)	99.5	N/A	N/A
#1 kiln nodule cooler scrubber	Custom-fabricated jet eductor scrubber	1575 (56,000)	99.6	N/A	N/A
#2 kiln nodule cooler scrubber	Custom-fabricated jet eductor scrubber	1575 (56,000)	99.7	N/A	N/A
#3 kiln nodule cooler scrubber	Custom-fabricated jet eductor scrubber	1575 (56,000)	99.6	N/A	N/A

(1) Information obtained from Tennessee Department of Public Health - Bureau of Environmental Health Services and Ref. [10].

(2) Information not available (N/A).

Table 4-32. Monsanto-Tennessee Nodule Sizing System Scrubbers(1).

Emission Point	Mfr. & Model No.	Gas Flow ACMM (ACFM)	Efficiency (%)	**Water Rate(2) l/s (gpm)**	ΔP (2) cm (in) W.G.
#1 nodule sizing system scrubber	American Air Filter Size 9 Type R Rotoclone wet centrifugal collector	985 (35,000)	98	7.5 (120)	11.5 (4.5)
#2 nodule sizing system scrubber	American Air Filter Size 9 Type R Rotoclone wet centrifugal collector	1126 (40,000)	98	8.8 (140)	14-15 (5.5-6.0)
#3 nodule sizing system scrubber	American Air Filter Size 9 Type R Rotoclone wet centrifugal collector	1210 (43,000)	98	9.4 (150)	16.5 (6.5)

(1) Information obtained from Tennessee Department of Public Health - Bureau of Environmental Health Services and Ref. [10].

(2) Information not available (N/A).

and the coke screen. Particulate removal efficiencies for these baghouses are not available. Coke used at the plant is processed in the coke dryer, which uses a cyclone and custom-fabricated wet venturi scrubber for offgas control. Particulate removal efficiency for the venturi scrubber is 99+ percent. Detailed design data for the proportioning area and coke handling airborne emission control equipment are summarized in Table 4-33.

Furnace and Offgas Filtration Systems

The central furnace stocking system supplies furnace feed to each of six stocking systems associated with the six furnaces. Dust from the hooded belt conveyer and transfer points are vented to two baghouse collectors for particulate removal. Each baghouse controls offgases from three furnaces. Particulate removal efficiency for the North furnace baghouse (#1, 2, 3 furnaces) is approximately 99.95 percent and for the South furnace baghouse (#4, 5, 6 furnaces) is approximately 99.96 percent.

Each furnace is equipped with a hooded vent system for collecting slag and ferrophosphorus taphole fumes (approximately 28 weight percent of the particles are smaller than 12 μm [10]). Taphole fumes collected by each system are treated by a custom-fabricated high-pressure wet venturi scrubber (six total) for particulate removal and are discharged to the atmosphere. Particulate removal efficiencies for these venturi scrubbers are not available.

The furnace offgases are drawn through cyclone dust collectors (on four furnaces) or Monsanto proprietary dust removal systems (on two furnaces) for particulate removal. The cleaned gases are then routed through water spray condensers before being flared or recycled to the kilns as fuel. Each furnace offgas system uses a CO flare vent system controlled by a wet scrubber. Particulate removal efficiencies for these scrubbers are approximately 99.5 percent. Detailed design data for the furnace and offgas filtration scrubbers are summarized in Table 4-34.

The condensed phosphorus is collected in tanks, sent to settling tanks for sludge and phossy water removal, and then pumped to underwater storage. The stored phosphorus is bottom loaded into water-sealed railroad cars for shipment to Monsanto chemical plants where it is combined with other elements to make various phosphate compounds. No emission control equipment is used with phosphorus handling activities.

Table 4-33. Monsanto-Tennessee Feed Proportioning and Coke Handling Airborne Emission Control Equipment(1).

Emission Point	Mfr. & Model No.	Gas Flow ACMM (ACFM)	Efficiency (%)	Water Rate l/s (gpm)	Air to Cloth Ratio(2)	$\Delta P^{(2)}$ cm (in) W.G.
North scaleroom baghouse	Lear Siegler/Luhr filter system, model EKD	425 (15,000)	99.95	-	N/A	N/A
South scaleroom baghouse	Lear Siegler/Luhr filter system, model EKD	651 (23,000)	99.95	-	N/A	N/A
North burden transfer baghouse	Lear Siegler/Luhr filter system, model EKD	368 (13,000)	99.97	-	N/A	N/A
South burden transfer baghouse	American Air Filter bag filter system	142 (5,000)	99.97	-	N/A	N/A
Central furnace stocking baghouse	Buell bag collector	425 (15,000)	99.94	-	N/A	N/A
Coke unloading area baghouse	N/A	340 (12,000)	N/A	-	N/A	N/A
Coke silo baghouse	N/A	43 (1500)	N/A	-	N/A	N/A
Coke screen baghouse	N/A	708 (25,000)	N/A	-	N/A	N/A
Coke dryer scrubber	Custom-fabricated wet venturi scrubber	623 (22,000)	99+	N/A	-	N/A

(1) Information obtained from Tennessee Department of Public Health - Bureau of Environmental Health Services and Ref. [10].

(2) Information not available (N/A).

Table 3-34. Monsanto-Tennessee Furnace and Offgas Filtration Scrubbers(1).

Emission Point	Mfr. & Model No.	Gas Flow ACMM (ACFM)	Efficiency (%)	Water Rate l/s (gpm)	Air to Cloth Ratio	ΔP cm (in) W. G.
North furnace stocking baghouse	N/A(2)	255 (9000)	99.95	-	N/A	N/A
South furnace stocking baghouse	N/A	212 (7500)	99.96	-	N/A	N/A
#1 through #6 furnace taphole fume scrubbers (each)	Custom-fabricated wet venturi scrubber	736 (26,000)	N/A	N/A	-	N/A
#1 and #5 furnace offgas systems (each)	Custom-fabricated water spray condenser	23 (800)	99.99	N/A	-	N/A
#2, 3, 4, and 6 furnace offgas systems (each)	Custom-fabricated water spray condenser	14 (480)	99.99	N/A	-	N/A
#1 and #3 furnace CO flares	Custom-fabricated wet scrubbers (two)	23 (800)	99.5	N/A	-	N/A
#2, 4, 5, and 6 furnace CO flares	Custom-fabricated wet scrubbers (four)	49 (1700)	99.5	N/A	-	N/A

(1) Information obtained from Tennessee Department of Public Health - Bureau of Environmental Health - Bureau of Environmental Health Services and Ref. [10].

(2) Information not available (N/A).

Fugitive Emission Sources

The fugitive emission sources at the Monsanto-Tennessee plant were identified and discussed in Chapter 3. Fugitive dust emissions from roadways are controlled by using a water truck.

4.3.5.2 Costs

The costs for the emission control techniques and equipment used by the Monsanto-Tennessee plant are based on plant wide capital and operating cost data furnished by the company. Table 4-35 summarizes the capital, operating, and maintenance costs for the specific major emission source areas. The individual system capital costs were estimated on the basis of methdology presented in Ref. [6] and adjusted to 1983 dollars consistent with the company-furnished data. Annual maintenance costs were assumed to be 7 percent of total capital costs. The total operating costs were furnished by the company as total 1981 operating and maintenance costs for all forms of pollution abatement. Operating costs were obtained by considering the portion of total costs associated with airborne emission control equipment and adjusting to 1983 dollars.

Table 4-35. Monsanto-Tennessee Estimated Airborne Emission Control Equipments Costs in 1983 Dollars.

Emission Source	Control Equipment	Auxiliary Equipment	Capital[1,2] Cost	Annual[2] Operating Cost	Annual[3] Maintenance Cost
#1 rotary kiln and #1 nodule cooler	Cyclone, spray tower scrubber w/demister, jet eductor scrubber	Fans, pumps, stacks	839,700	169,300	58,700
#2 rotary kiln and #2 nodule cooler	Cyclone, spray tower scrubber w/demister, jet eductor scrubber	Fans, pumps, stacks	848,200	171,300	59,400
#3 rotary kiln and #3 nodule cooler	Cyclone, spray tower scrubber w/demister, jet eductor scrubber	Fans, pumps, stacks	877,100	177,200	61,400
#1 nodule sizing system	American Air Filter Rotoclone	Stack	73,600	14,900	5,200
#2 nodule sizing system	American Air Filter Rotoclone	Stack	76,800	15,500	5,400
#3 nodule sizing system	American Air Filter Rotoclone	Stack	82,500	16,700	5,800
Coke drying and sizing system	Coke dryer cyclone, venturi scrubber, cyclone separator, coke screen baghouse, coke silo baghouse, coke unloading area baghouse	Hoods, fans, pump, stacks	864,900	174,700	60,500
Feed proportioning system	Lear Siegler/Luhr filter systems (two)	Fans, stacks	557,100	112,500	39,000
Feed transfer system	Lear Siegler/Luhr system, American Air Filter bag filter, and Buell bag filter	Fans, stacks	632,300	127,700	44,300
Furnace feed systems	Bag filter systems (two)	Fans, stacks	348,600	70,400	24,400
#1 furnace tapping system offgas	Venturi scrubber, cyclonic separator	Pump, fan, stack	245,400	49,600	17,200
#2 furnace tapping system offgas	Venturi scrubber, cyclonic separator	Pump, fan, stack	245,400	49,600	17,200

Table 4-35. Monsanto-Tennessee Estimated Airborne Emission Control Equipment Costs in 1983 Dollars. (Continued)

Emission Source	Control Equipment	Auxiliary Equipment	Capital(1,2) Cost	Annual(2) Operating Cost	Annual(3) Maintenance Cost
#3 furnace tapping system offgas	Venturi scrubber, cyclonic separator	Pump, fan, stack	245,400	49,600	17,200
#4 furnace tapping system offgas	Venturi scrubber, cyclonic separator	Pump, fan, stack	245,400	49,600	17,200
#5 furnace tapping system offgas	Venturi scrubber, cyclonic separator	Pump, fan, stack	245,400	49,600	17,200
#6 furnace tapping system offgas	Venturi scrubber, cyclonic separator	Pump, fan, stack	245,400	49,600	17,200
#1 furnace offgas system	Cyclone, spray tower/ condenser system	Fan, pump, stack	191,300	38,600	13,400
#2 furnace offgas system	Cyclone, spray tower/ condenser system	Fan, pump, stack	197,600	39,900	13,800
#3 furnace offgas system	Cyclone, spray tower/ condenser system	Fan, pump, stack	191,300	38,600	13,400
#4 furnace offgas system	Cyclone, spray tower/ condenser system	Fan, pump, stack	197,600	39,900	13,800
#5 furnace offgas system	Cyclone, spray tower/ condenser system	Fan, pump, stack	197,600	39,900	13,800
#6 furnace offgas system	Cyclone, spray tower/ condenser system	Fan, pump, stack	197,600	39,900	13,800
#1 furnace CO flare	Wet scrubber	Fan, pump, stack	29,500	6,000	2,100
#2 furnace CO flare	Wet scrubber	Fan, pump, stack	25,600	5,200	1,800

Table 4-35. Monsanto-Tennessee Estimated Airborne Emission Control Equipment Costs in 1983 Dollars. (Continued)

Emission Source	Control Equipment	Auxiliary Equipment	Capital(1,2) Cost	Annual(2) Operating Cost	Annual(3) Maintenance Cost
#3 furnace CO flare	Wet scrubber	Fan, pump, stack	27,400	5,500	1,900
#4 furnace CO flare	Wet scrubber	Fan, pump, stack	26,800	5,400	1,900
#5 furnace CO flare	Wet scrubber	Fan, pump, stack	40,800	8,200	2,900
#6 furnace CO flare	Wet scrubber	Fan, pump, stack	27,400	5,500	1,900
		Plant totals	8,023,700	1,620,400	561,800

(1) Capital costs adjusted to 1983 dollars based on the Chemical Engineering Plant Cost Index [5].

(2) Developed using the methodology presented in Ref. [6] and adjusted to 1983 dollars.

(3) Assumed to be 7 percent of capital costs.

4.3.6 Monsanto Plant - Soda Springs, Idaho

4.3.6.1 Techniques and Equipment

Point sources of airborne emissions from the Monsanto-Idaho plant were identified in Table 3-33 together with a general listing of the associated emission control techniques and equipment. Additional technical information is summarized in Table 4-36 for the major emission control systems. The Monsanto-Idaho plant operates with a state permit limiting particulate emissions and fluoride emissions according to the regulations of the Idaho Department of Health and Welfare - Division of Environment. When visible emissions from the baghouses exceed 5 percent opacity, Monsanto is required to initiate appropriate corrective action to reduce the opacity to 5 percent or below. Point sources of airborne emissions required to comply with applicable limitations and standards are either periodically stack tested for compliance certification or monitored for compliance by visual opacity readings.

Kiln and Nodule Cooler Systems

Kiln feed ore is initially blended by the stockpiling process at the raw materials craneway and is further blended by reclaiming. The blended ore is fed to the rotary kiln by a hooded belt conveyer. No airborne emission controls are used with these ore handling processes.

The kiln offgas is vented into a sequential offgas treatment operation consisting of a knockout chamber, a spray tower scrubber, and demister stack. The wet scrubber uses a lime scrubbing liquor to remove fluorine, SO_2, and particulates. The kiln demister is a wooden structure resembling a water tank. Water-laden gases from the scrubber enter the tank tangentially and swirl to remove moisture and particulates before being vented. Spray tower slurry is sent to dewatering ponds from which solids are reclaimed. Particulate removal efficiency for the knockout chamber is 10 to 15 percent and for the kiln spray tower and demister is approximately 99.9 percent.

The hot nodules leaving the kiln pass through a moving grate nodule cooler before being conveyed to the nodule sizing system. Offgas from the nodule cooling operation is vented to a spray tower scrubber and a demister stack. The wet scrubber uses a lime scrubbing liquor for fluorine,

Table 4-36. Monsanto-Idaho Airborne Emission Control Techniques and Equipment(1).

Emission Point	**Emission Source**	Type of Equipment	Maintenance(2)	**Dust Disposal**	**Scrubbing Media**
Kiln offgas scrubber	Kiln offgas	Custom-fabricated spray tower scrubber	N/A	-	Recycled process water plus lime
Nodule cooler offgas scrubber	Kiln nodule cooling operation	Custom-fabricated spray tower scrubber	N/A	-	Recycled process water plus lime
Nodule sizing scrubber	Nodule crushing and screening operation	Custom-fabricated wet venturi scrubber	N/A	-	Recycled process water plus lime
Coke bunker baghouse	Coke storage and transfer operations	Reverse jet bag collector	N/A	Landfill	-
Coke handling and sizing baghouse	Coke crushing and screening operations	Reverse jet bag collector	N/A	Dust sent to pond	-
Silica handling baghouse	Silica handling and scaleroom handling operations	Reverse jet bag collector	N/A	Dust sent to pond	-
Coke and silica bunker	Coke and silica loading operations	Reverse jet bag collector	N/A	Landfill	-
Coke/silica dryer offgas scrubber	Coke/silica drying operation	Custom-fabricated spray tower scrubber	N/A	-	Recycled non-contact cooling water
Burden transfer baghouse	Burden transfer operations	Reverse jet bag collector	N/A	Dust recycled to kiln feed	-
Furnace burden bin baghouses	Burden bin material handling	Reverse jet bag collector	N/A	Dust recycled to kiln feed	-
Furnace taphole fume scrubbers	Slag and ferrophosphorus tapping operations	Custom-fabricated wet venturi scrubbers	N/A	-	Recycled process water plus soda ash
Furnace offgas condensers	Furnace offgas condensing operations	Custom-fabricated water spray towers	N/A	-	Recycled process water plus soda ash

(1) Information obtained from Idaho Department of Health and Welfare - Division of Environment.

(2) Preventive maintenance information not available (N/A). Corrective maintenance assumed upon periodic inspection or as needed.

SO_2, and particulate removal. The nodule cooler demister is a wooden structure similar to the kiln demister, with a particulate removal efficiency of 98.8 percent. Detailed design data for the kiln offgas and nodule cooler scrubbers are summarized in Table 4-37.

Nodule Sizing and Feed Proportioning Area Systems

The nodule sizing system consists of double-roll crushing and screening operations. Offgases from these operations are vented to a treatment system consisting of a custom-fabricated wet venturi scrubber followed by a cyclonic separator. Total particulate removal efficiency for the venturi scrubber is approximately 99.98 percent. Nodule fines are stored before being reclaimed for recycle to the kiln feed.

Following sizing, the nodular material is stored and transferred by hooded conveyer to the proportioning building as needed. Coke is dried and sized on site and the sized coke is stored in bins feeding the burden scales. Offgases from the hooded material handling and transfer operations at the coke bunker are controlled by a baghouse. Offgases collected from the hooded coke crushing and screening operations are also controlled by a baghouse. In addition, on-site silica handling and transfer operations are controlled by a third baghouse. Total particulate removal efficiencies for the baghouses are approximately 99.9 percent.

Coke and silica are dried using the same rotary dryer. Offgases from the rotary dryer are vented to a custom-fabricated spray tower scrubber, with a particulate removal efficiency of approximately 99.6 percent. Dried coke and silica are transferred by hooded conveyer to the scaleroom where coke, silica, and nodules are mixed using a proportioning weighing system. A belt conveyer moves beneath weigh bins that transfer the raw materials to it. The belt is covered and emissions are vented to the silica handling system baghouse. Detailed design data for the nodule sizing and feed proportioning area airborne emission control equipment are summarized in Table 4-38.

Burden Area and Furnace and Offgas Filtration Systems

Burden material is moved by hooded belt conveyer from the proportioning area to one of three burden bins in the stocking system located above the three furnaces. Offgases from operations in and around this sytem

Table 4-37. Monsanto-Idaho Kiln Offgas and Nodule Cooler Scrubbers(1).

Emission Point	Mfr. & Model No.	Gas Flow ACMM (ACFM)	Efficiency (%)	Water Rate l/s (gpm)	ΔP cm (in) W.G.
Kiln offgas scrubber	Custom-fabricated spray tower scrubber	9006 (318,000)	99.9	N/A(2)	N/A
Nodule cooler offgas scrubber	Custom-fabricated spray tower scrubber	9685 (342,000)	99.9	N/A	N/A

(1) Information obtained from Idaho Department of Health and Welfare - Division of Environment.

(2) Information not available (N/A).

Table 4-38. Monsanto-Idaho Nodule Sizing and Feed Proportioning Airborne Emission Control Equipment[1].

Emission Point	Mfr. & Model No.	Gas Flow ACMM (ACFM)	Efficiency (%)	Water Rate l/s (gpm)	Air to Cloth Ratio	ΔP cm (in) W.G.
Nodule sizing scrubber	Custom-fabricated wet venturi scrubber	4191 (148,000)	99.9	N/A[2]	-	41 (16) min.
Coke bunker baghouse	N/A	708 (25,000)	99.9	-	N/A	N/A
Coke handling and sizing baghouse	N/A	708 (25,000)	99.9	-	N/A	N/A
Silica handling baghouse	N/A	708 (25,000)	99.9	-	N/A	N/A
Coke and silica hopper baghouse	N/A	708 (25,000)	99.9	-	N/A	N/A
Coke/silica dryer offgas scrubber	Custom-fabricated spray tower scrubber	1275 (45,000)	99.6	N/A	-	N/A

(1) Information obtained from Idaho Department of Health and Welfare - Division of Environment.

(2) Information not available (N/A).

are controlled by four baghouses. One baghouse controls emissions from transfer points in the system, and three baghouses control emissions at the top of the three burden bins. Feed dust removed by these baghouses is landfilled. Particulate removal efficiencies for these baghouses are 99.9 percent.

The slag and ferrophosphorus tapping operations for each furnace are vented into separate offgas treatment systems consisting of a custom-fabricated wet venturi scrubber followed by a cyclonic separator before discharge to the atmosphere. Particulate removal efficiencies for these scrubbers are approximately 95 percent. Furnace offgases are drawn through electrostatic precipitator dust collectors (one per furnace) for particulate removal. Dust removed in these collectors is passed through a burning process to convert it to a salable product. Offgases from this burning process are vented to the furnace taphole fume scrubbing systems for particulate removal. Furnace gases leaving the electrostatic precipitators are sent through water spray tower condensers (one per furnace) where the gases are cooled and the phosphorus condenses. Condenser offgases are either recycled to the kiln as fuel or flared to the atmosphere. Detailed design data for the furnace and offgas filtration systems airborne emission control equipment are summarized in Table 4-39.

The condensed phosphorus is collected in tanks, sent to settling tanks for sludge and phossy water removal, and then pumped to underwater storage. The stored phosphorus is bottom loaded into water-sealed railroad cars for shipment to Monsanto chemical plants where it is combined with other elements to make various phosphate compounds. No emission control equipment is used with phosphorus handling activities.

Fugitive Emission Sources

The fugitive emission sources at the Monsanto-Idaho plant were identified and discussed in Chapter 3. Fugitive dust emissions from roadways are controlled by using a water truck.

4.3.6.2 Costs

The costs for the emission control techniques and equipment used by the Monsanto-Idaho plant are based on capital cost data furnished by the company. Table 4-40 summarizes the capital, operating, and maintenance

Table 4-39. Monsanto-Idaho Furnace and Offgas Filtration Airborne Emission Control Equipment[1].

Emission Point	Mfr. & Model No.	Gas Flow ACMM (ACFM)	Efficiency (%)	Water Rate l/s (gpm)	Air to Cloth Ratio	ΔP cm (in) W.G.
Burden transfer baghouse	N/A[2]	N/A	N/A	-	N/A	N/A
#7, 8 and 9 furnace burden bin baghouses (each)	N/A	N/A	N/A	-	N/A	N/A
#7 furnace taphole fume scrubber	Custom-fabricated wet venturi scrubber	765 (27,000)	95	28 (450)	-	132 (52) min.
#8 furnace taphole fume scrubber	Custom-fabricated wet venturi scrubber	765 (27,000)	95	28 (450)	-	132 (52) min.
#9 furnace taphole fume scrubber	Custom-fabricated wet venturi scrubber	765 (27,000)	95	28 (450)	-	132 (52) min.
#7, 8 and 9 furnace offgas systems (each)	Custom-fabricated water spray tower condenser	N/A	N/A	N/A	-	N/A

(1) Information obtained from Idaho Department of Health and Welfare - Division of Environment.

(2) Information not available (N/A).

Table 4-40. Monsanto-Idaho Estimated Airborne Emission Control Equipment Costs in 1983 Dollars.

Emission Source	Control Equipment	Auxiliary Equipment	Capital[(1)] Cost	Annual Operating Cost	Annual Maintenance Cost
#5 rotary kiln	Knockout chamber, spray tower scrubber w/demister	Fan, pump, hoods, ducts, stack	518,000	462,900	22,800
Nodule cooler	Spray tower scrubber w/demister	Fan, pump, stack	2,727,000	462,900	22,800
Nodule sizing system	Venturi scrubber, cyclonic separator	Pump, fan, ducts, stack	4,090,000	479,100	23,400
Silica handling system - scaleroom	Baghouse filter	Ducts, hoods, fan, stack	1,102,000	304,500	15,000
Coke handling and sizing system	Baghouse filter	Ducts, hoods, fan, stack	1,102,000	481,200	23,700
Coke bunker	Baghouse filter	Ducts, hoods, fan, stack	1,102,000	20,000	1,400
Coke/silica bunker	Baghouse filter	Ducts, hoods, fan, stack	1,102,000	40,600	2,000
Coke/silica drying system	Spray tower scrubber	Fan, pump, stack	137,000	255,800	12,600
Feed transfer and stocking system	Baghouse filters (four)	Hoods, ducts, stacks	5,500,000	341,000	16,300
#7 furnace tapping system	Venturi scrubber, cyclonic separator	Pump, fan, duct, hoods, stack	5,154,000	238,200	35,200
#8 furnace tapping system	Venturi scrubber, cyclonic separator	Pump, fan, duct, hoods, stack	5,154,000	238,200	35,200
#9 furnace tapping system	Venturi scrubber, cyclonic separator	Pump, fan, duct, hoods, stack	5,154,000	238,200	35,200

Table 4-40. Monsanto-Idaho Estimated Airborne Emission Control Equipment Costs in 1983 Dollars. (Continued)

Emission Source	Control Equipment	Auxiliary Equipment	Capital[1] Cost	Annual Operating Cost	Annual Maintenance Cost
#7 furnace offgas system	ESP, water spray tower condenser	Fan, pump, stack, tanks	3,415,000	149,600	22,100
#8 furnace offgas system	ESP, water spray tower condenser	Fan, pump, stack tanks	3,415,000	149,600	22,100
#9 furnace offgas system	ESP, water spray tower condenser	Fan, pump, stack tanks	3,415,000	149,600	22,100
		Plant totals	43,087,000	4,015,400	312,400

(1) Capital costs adjusted to 1983 dollars based on the Chemical Engineering Plant Cost Index [5].

costs for the specific major emission source areas. The individual system capital costs were estimated from the company-furnished data and supplemented on the basis of methodology presented in Ref. [6] before being adjusted to 1983 dollars.

4.3.7 Mobil Chemical Plant - Pierce, Florida

4.3.7.1 Techniques and Equipment

Point sources of airborne emissions from the Mobil Chemical plant were identified in Table 3-38 together with a general listing of the associated emission control techniques and equipment. Additional technical information is summarized in Table 4-41 for the major emission control systems. When operating, the Mobil Chemical plant operates with a state permit limiting particulate emissions according to Chapters 17-2 and 17-4 of the Florida Administrative Code - Rules of the Florida Department of Environmental Regulation. Point sources of airborne emissions required to comply with applicable limitations and standards are monitored for compliance of annual stack testing and visual opacity readings.

Ore Handling and Briquetting Systems

Washed ore stockpiled at the plant is dried before being sent to the briquetting system. Offgas from the ore dryer is treated sequentially by twin parallel cyclones, a venturi scrubber, and a cyclone mist separator. Approximately 85 percent of the dry particulate dust is removed by the cyclones and recycled back to the briquetting system for reprocessing. The venturi scrubber operates with approximately a 40 cm (16 in) W. G. pressure drop and at an efficiency of approximately 90 percent. The cyclonic mist separator also operates at approximately 90 percent efficiency.

Dried ore and recycled phosphate fines and dust are subsequently treated with phosphoric acid and formed into briquettes. Briquettes are sent through a traveling grate calciner for drying and sintering. Offgases from the calciner consist of the normal combustion products evolved when CO gas is ignited in the presence of excess air, plus fluorine, particulates, and water vapor. The offgases are initially treated in twin parallel cyclones (Buell) to remove the bulk of large particulate solids. This equipment operates at approximately 85 percent efficiency and removes particulates larger than 10 μm. The gases then pass into a vertical custom-fabricated scrubber leg where they are contacted with sprayed water to remove about half the fluorine and particulates larger than 10 μm still present. Following the vertical scrubber leg, the gases enter the first stage wet cyclonic scrubber where fine downward water sprays and cyclonic

Table 4-41. Mobil Chemical Airborne Emission Control Techniques and Equipment[1].

Emission Point	Emission Source	Type of Equipment	Maintenance	Dust Disposal	Scrubbing Media
Ore dryer scrubber	Phosphate ore (rock) dryer	Hydronics custom-fabricated wet venturi scrubber	N/A[2]	-	Recycled process water
Traveling grate calciner scrubbers (three)	Briquette calciner offgas	Hydronics custom-fabricated vertical wet scrubber leg	N/A	-	Recycled process water
		Custom-fabricated wet (spray) cyclonic separators (two)	N/A	-	Recycled process water plus fresh water
Feed proportioning area baghouse	Feed proportioning area fugitive dust	Sly Multi-Seal Dynaclone	N/A	Recycled to briquetting system feed	-
Coke dryer scrubber	Coke dryer offgas	AAF Type R Rotoclone wet centrifugal collector with Kimre tail gas scrubber		-	Recycled process water plus mist eliminator mesh packing
#2, 3 furnace taphole fume scrubbers (two)	Furnace slag and ferrophosphorus tapping	Hydronics custom-fabricated wet venturi scrubbers	N/A	-	Recycled process water
Furnace offgas condenser scrubbers (two)	Furnace offgas condenser	Vertical nozzle spray spray scrubbers	N/A	-	Recycled process water

(1) Information obtained from Florida Department of Environmental Regulation and from data presented to SAI staff at October 28-29, 1982, meeting at Mobil Chemical plant in Pierce, Florida.

(2) Preventive maintenance information not available (N/A). Corrective maintenance assumed upon periodic inspection or as needed.

action further remove contaminants. This scrubber is a rubber-lined vessel with an efficiency of approximately 80 percent for particulates larger than 3 µm. Finally, the gases pass into the second stage wet cyclonic scrubber for after-scrubbing with fresh water fine upward spray treatment and cyclonic action before release to the atmosphere. This scrubber is also rubber lined and operates with an efficiency of approximately 90 percent for the remaining particulates. All these wet scrubbers use treated, recirculated process water. The scrubber effluent waters are neutralized with lime and then allowed to settle in a closed serpentine pond before being pumped back for reuse. Detailed design data for the ore handling and briquetting emission control systems are summarized in Table 4-42.

Feed Proportioning Area

Briquettes are screened in the feed proportioning area and blended with dried ore (directly from the ore dryer), sized coke, and silica via a feed proportioning belt. Coke sent to the feed proportioning area is dried and sized on site. Fugitive dust from operations in the feed proportioning area is collected by a Sly Multi-Seal Dynaclone bag collector. Dust removal from the filter bags is accomplished by reverse cleaning air. Approximately 99.9 percent of the particulates larger than 0.5 µm are collected in this system.

The coke sent to the feed proportioning area is first dried in a rotary dryer fueled by recycled CO gas from the furnaces. Dryer exhaust gases laden with particulates are routed to an American Air Filter Rotoclone wet scrubber fitted with a Kimre tail gas wet scrubber. The Kimre scrubber is a vessel containing mesh mist eliminator packing. The entire system operates with an efficiency of approximately 99 percent for the particulates larger than 3 µm. Detailed design data for the feed proportioning area and coke dryer emission control equipment are summarized in Table 4-43.

Furnace and Offgas Filtration Systems

During furnace tapping operations, fumes containing particulates and fluorides are captured by hooded vent systems installed over the tap holes of each furnace. The vent gases from each furnace pass through separate custom-fabricated wet venturi scrubbers and into a common cyclonic separator before discharge to the atmosphere. Approximately 98 percent of

Table 4-42. Mobil Chemical Ore Handling and Briquetting System Scrubbers(1).

Emission Point	Mfr. & Model No.	Gas Flow ACMM (ACFM)	Efficiency (%)	Water Rate l/s (gpm)	ΔP cm (in) W.G.
Ore dryer scrubber	Hydronics wet venturi scrubber	991 (35,000)(2)	90	N/A(3)	40 (16)
Traveling grate calciner	Hydronics custom-fabricated wet scrubber	1982 (70,000)	50 (+10 μm)	N/A	N/A
	Custom-fabricated first stage wet cyclonic separator	1500 (53,000)	80 (+3 μm)	14.1 (225)	N/A
	Custom-fabricated second stage wet cyclonic separator	1487 (52,500)	90	6.2 (100)	N/A

(1) Information obtained from Florida Department of Environmental Regulation and from data presented to SAI staff at October 28-29, 1982, meeting at Mobil Chemical plant in Pierce, Florida.

(2) Estimated.

(3) Information not available (N/A).

Table 4-43. Mobil Chemical Feed Proportioning Area Airborne Emission Control Equipment(1).

Emission Point	Mfr. & Model No.	Gas Flow ACMM (ACFM)	Efficiency (%)	Water Rate l/s (gpm)	Air to Cloth Ratio	ΔP cm (in) W.G.
Feed proportioning area baghouse	Sly Multi-Seal Dynaclone model #30	1133 (40,000)	99.9 (+1/2 μm)	-	3.6/1	N/A
Coke dryer scrubber	American Air Filter size 5 Type R Rotoclone wet centrifugal collector	651 (23,000)	98	6.2 (100)	-	15 (6)(2)
	Kimre tail gas scrubber	510 (18,000)	99 (+3 μm)	6.2 (100)	-	6 (2.5)(2)

(1) Information obtained from Florida Department of Environmental Regulation and from data presented to SAI staff at October 28-29, 1982, meeting at Mobil Chemical plant in Pierce, Florida.

(2) Estimated based on vendor literature.

the particulates larger than 1 μm are removed in the wet venturi scrubbers and 99 percent of the saturated liquid droplets larger than 5 μm are removed in the cyclonic separator. Overflow effluent from the scrubber is discharged into the plant cooling water system, which is routed to plant ponds for recirculation and reuse.

The furnace offgases are routed to a condenser where phosphorus is condensed by passage over water through two parallel banks of air-cooled tubes. Each bank has 28 vertical 0.78-m diameter tubes. After the phosphorus is condensed, the gases are treated by two steps of water spray tower scrubbing. The cooled CO is routed to the ore dryer, coke dryer, and traveling grate calciner for use as fuel. Detailed design data for the furnace and offgas filtration emission control systems are summarized in Table 4-54.

Fugitive Emmission Sources

The fugitive emission sources at the Mobil Chemical plant were identified and discussed in Chapter 3. Fugitive dust emissions from the plant area are controlled by using water spray nozzles mounted around the plant area.

4.3.7.2 Costs

The costs for the emission control techniques and/or equipment used by Mobil Chemical at this plant are based primarily on data furnished by the company and adjusted to 1983 dollars. Table 4-45 summarizes the capital, operating, and maintenance costs for the specific major air pollution source areas. Adjustment of the cost data to 1983 values was based on the Chemical Engineering Plant Cost Index [5].

Table 4-44. Mobil Chemical Furnace and Offgas Filtration Scrubbers(1).

Emission Point	Mfr. & Model No.	Gas Flow ACMM (ACFM)	Efficiency (%)	Water Rate l/s (gpm)	ΔP cm (in) W.G.
#2, 3 furnace taphole fume scrubbers (two)	Hydronics custom-fabricated wet venturi scrubbers	1020 (36,000)	98 (+1 μm)	22 (350)	38 (15)
Furnace offgas condenser scrubbers(2) (two)	Vertical nozzle spray scrubber	142 (5000)	N/A	4.7 (75)	N/A

(1) Information obtained from Florida Department of Environmental Regulation and from data presented to SAI staff at October 28-29, 1982, meeting at Mobil Chemical plant in Pierce, Florida.

Table 4-45. Mobil Chemical Estimated Airborne Emission Control Equipment Costs in 1983 Dollars.

Emission Source	Control Equipment	Auxiliary Equipment	Capital[(1,2)] Cost	Annual[(2)] Operating Cost	Annual[(2)] Maintenance Cost
Rock drying system	Parallel cyclones (two), Hydronics venturi scrubber, cyclone separator	Fan, pump, tank, stack	166,600	38,900	16,000
Traveling grate calciner system	Parallel cyclones (two), Hydronics wet scrubber leg, wet cyclone separators (two in series)	Fan, pumps, stack	531,600	122,900	49,000
Feed proportioning area	Sly Multi-Seal Dynaclone bag filter	Fan	300,800	69,700	28,000
Coke drying, sizing and handling system	American Air Filter Rotoclone, Kimre tail gas scrubber w/mist eliminator	Fan, pump, stack	143,200	33,500	14,000
#2 & #3 furnace offgas system	Air-cooled condensers (56 tubes), vertical spray scrubbers (two in series)	Fan, stack	704,800	162,600	64,700
#2 & #3 furnace slag and ferrophosphorus tapping system	Hydronics venturi scrubbers (two), cyclonic separator	Fan, pump, tanks, stack	314,700	72,400	28,300
		Plant Totals	2,161,700	500,000	200,000

(1) Capital costs adjusted to 1983 dollars based on the Chemical Engineering Plant Cost Index [5].

(2) Developed using the methodology presented in Ref. [6] and adjusted to 1983 dollars.

4.3.8 Occidental Chemical Plant - Columbia, Tennessee

4.3.8.1 Techniques and Equipment

Point sources of airborne emissions from the Occidental Chemical plant were identified in Table 3-43 together with a general listing of the associated emission control techniques and equipment. Additional technical information is summarized in Table 4-46 for the major emission control systems. The Occidental Chemical plant operates with a state permit limiting particulate emissions according to Chapter 1200 of "Rules of Tennessee Department of Public Health" - Bureau of Environmental Health Services - Division of Air Pollution Control. Point sources of airborne emissions required to comply with applicable limitations and standards are monitored for compliance by visual opacity readings. Although not required, stack emissions are tested periodically.

Rotary Kiln System

Washed ore stockpiled at the plant is transported to an inclined belt conveyer which feeds the #4 rotary kiln for ore nodulization. There are two kilns at the Occidental Chemical plant, but the #1 rotary kiln has not operated since 1981 and there are no plans to reactivate it in the foreseeable future. No airborne emission controls are used with the ore handling processes. Offgas from the #4 kiln is vented to a treatment system consisting of eight high-efficiency cyclones operating in parallel. Approximately 90 percent of the dust is removed in this step. The remaining dust (36 weight percent >40 μm, 64 weight percent 1-40 μm) and gases are passed through 4 low-energy jet venturi type scrubbers operating in parallel [11]. The venturi scrubbers use a lime scrubbing liquor to remove fluorides, SO_2, and the remaining dust. The lime bin at the #4 kiln uses a baghouse for particulate control. In addition, emissions at the unslaked lime storage tank are controlled by a baghouse.

The currently inactive #1 kiln uses two cyclones followed by a spray tower scrubber for offgas particulate control. Detailed design data for the kiln and lime emission control systems are summarized in Table 4-47.

Table 4-46. Occidental Chemical Airborne Emission Control Techniques and Equipment(1).

Emission Point	Emission Source	Type of Equipment	Maintenance(2)	Dust Disposal	Scrubbing Media
#4 kiln offgas scrubbers (four)	#4 kiln offgas	Jet venturi scrubber	N/A	-	Recycled process water plus lime
#4 kiln cooler scrubbers (four)	#4 kiln nodule cooling/sizing operations	Jet venturi scrubber	N/A	-	Recycled process water
#4 kiln nodule crushers/conveyers scrubber	#4 kiln nodule sizing operations	AAF Type R Rotoclone wet centrifugal collector	N/A	-	Recycled process water
Lime bin baghouse	#4 kiln lime bin	Carter-Day pulse filter collector	N/A	Recycled back to process	-
Unslaked lime storage baghouse	Lime storage tank	Premier Pneumatics dust collector	N/A	Recycled back to process	-
#1 kiln offgas scrubber (inactive)	#1 kiln offgas	Spray tower scrubber	N/A	-	Recycled process water plus lime
Coke fines hopper baghouse	Coke fines hopper	Flex-Kleen pulse filter collector	N/A	Recycled back to process	-
Coke dryer scrubber	Coke dryer	Ducon VVO venturi scrubber	N/A	-	Recycled process water plus fresh water
Proportioning area burden tunnel scrubber	Burden handling/transfer	Ducon VVO venturi scrubber	N/A	-	Recycled process water plus fresh water
Burden bin scrubbers (three, one per burden bin)	Burdening system	AAF Type R Rotoclone wet centrifugal collector	N/A	-	Recycled process water
#1 furnace offgas condensers (two)	#1 furnace offgas	Spray tower scrubber	N/A	-	Recycled process water plus fresh water
#2, 3 furnace offgas condensers (two per furnace)	#2, 3 furnace offgas	Spray tower scrubber	N/A	-	Recycled process water plus fresh water

Table 4-46. Occidental Chemical Airborne Emission Control Techniques and Equipment(1). (Cont'd)

Emission Point	Emission Source	Type of Equipment	Maintenance(2)	Dust Disposal	Scrubbing Media
#1 furnace evaporator and condenser sump	Phosphorus sludge treatment	AAF Kinpactor venturi scrubber	N/A	-	Recycled process water
Phosphorus sludge recover scrubber	Phosphorus sludge recovery tank	AAF Kinpactor venturi scrubber	N/A	-	Recycled process water
#2, 3 furnace sumps	Phosphorus collection	AAF Kinpactor venturi scrubber	N/A	-	Recycled process water
#1, 2, 3 furnace scrubbers (one per furnace)	Furnace slag and ferrophosphorus tapping	Air Pollution Industries venturi scrubber	N/A	-	Recycled process water
Ferrophosphorus ball mill baghouse (inactive)	Ferrophosphorus processing	Flex-Kleen pulse filter collector	N/A	Collected and sold	-
Ferrophosphorus ball mill product baghouse (inactive)	Ferrophosphorus processing	Flex-Kleen pulse filter collector	N/A	Recycled back to process	-
Phosphorus filter scrubber	Phosphorus filter area	AAF Kinpactor venturi scrubber	N/A	-	Recycled process water
Phosphorus loading scrubber	Phosphorus loading area	AAF Kinpactor venturi scrubber	N/A	-	Recycled process water

(1) Information obtained from Tennessee Department of Public Health - Bureau of Environment and from data presented to SAI staff at October 14-15, 1982, meeting at Occidental Chemical plant in Columbia, Tennessee.

(2) Preventive maintenance information not available (N/A). Corrective maintenance assumed upon periodic inspection or as needed.

Table 4-47. Occidental Chemical Kiln and Lime System Airborne Emission Control Equipment(1).

Emission Point	Mfr. & Model No.	Gas Flow ACMM (ACFM)	Efficiency (%)	Water Rate l/s (gpm)	Air to Cloth Ratio	ΔP cm (in) W.G.
#4 kiln offgas scrubbers (ea.)	Jet venturi type	1246 (44,000)	N/A	N/A	-	5-7.5 (2-3)
#1 kiln offgas scrubber (inactive)	Spray tower	1416 (50,000)	N/A	N/A	-	N/A
Lime bin baghouse	Carter-Day Model 24RJ60	85 (3000)	N/A	-	9.38/1	N/A
Unslaked lime storage tank baghouse	Premier Pneumatics Model BVC-S-250	N/A(2)	99+	-	(3)	N/A

(1) Information obtained from Tennessee Department of Public Health - Bureau of Environment and from data presented to SAI staff at October 14-15, 1982, meeting at Occidental Chemical plant in Columbia, Tennessee.

(2) Information not available (N/A).

(3) Uses 25 340-g polypropylene bags with 23.2 m^2 cloth filtering area.

Nodule Cooling and Sizing System

The hot phosphate nodules that leave the #4 kiln are cooled and sized in the nodule cooling and sizing operations following the kiln. Dust from the first stage cooling, screening, and crushing operation is collected by a hood system over the equipment and material transfer conveyers. This dust-laden gas is treated by four jet venturi type scrubbers operating in parallel followed by a separating tower and sump. Emissions from the final screening operation are controlled by two cyclones followed by an American Air Filter (AAF) Type R Rotoclone wet centrifugal collector. Detailed design data for the nodule cooling and sizing system emission control equipment are summarized in Table 4-48.

Feed Proportioning and Burdening Areas

The coke used in the feed proportioning area is obtained from a local coal company that processes the coke very near the plant. Although not part of Occidental Chemical plant operations, the coke is dried before transfer to an on-site storage silo. Emissions from the coke dryer are controlled by a wet venturi scrubber. The coke fines hopper is vented and has a baghouse filter treatment system for the offgas to remove coke dust generated during material transfer.

Feed material mixed by the proportioning weighing system is conveyed to the furnace burden bin. Dust generated during these material handling operations in the proportioning area are collected by hood systems and treated by a Ducon venturi scrubber/separator system. Each burden bin (three total) is vented and dust generated at the burden bins from material handling is treated by three AAF Type R Rotoclone wet centrifugal collectors (one per burden bin) for dust removed. Detailed design data for the feed proportioning area and burdening area emission control equipment are summarized in Table 4-49.

Furnace Operations

The burden mixture from each burden bin is gravity fed to one of three furnaces. Each furnace has its own system of taphole fume emission control equipment. This consists of hoods to collect the fumes drawn through a fixed throat Air Pollution Industries venturi scrubber (three total) followed by a cyclone separator. By-product ferrophosphorus

Table 4-48. Occidental Chemical Nodule Cooling and Sizing System Scrubbers(1).

Emission Point	Mfr. & Model No.	Gas Flow ACMM (ACFM)	Efficiency(2) (%)	Water Rate l/s (gpm)	ΔP cm (in) W.G.
#4 kiln cooler scrubbers (four)	Jet venturi type	1020 (36,000)	N/A	N/A	5-7.5 (2-3)
#4 kiln nodule crusher/conveyers scrubber	American Air Filter (AAF) Size 8 Type R Rotoclone wet centrifugal collector	990 (34,000)	98(3)	7.5 (120)(3)	15 (6)(3)

(1) Information obtained from Tennessee Department of Public Health - Bureau of Environment and from data presented to SAI staff at October 14-15, 1982, meeting at Occidental Chemical plant in Columbia, Tennessee.

(2) Information not available (N/A).

(3) Estimated based on vendor literature.

Table 4-49. Occidental Chemical Feed Proportioning and Burdening Airborne Emission Control Equipment(1).

Emission Point	Mfr. & Model No.	Gas Flow ACMM (ACFM)	Efficiency(2) (%)	Water Rate l/s (gpm)	Air to Cloth Ratio	ΔP cm (in) W.G.
Coke fines hopper baghouse	Flex-Kleen model 84-WRS-176 (2 units)	425 (15,000)	N/A	-	4.26/1	7.5-10 (3-4)
Coke dryer scrubber	Ducon VVO venturi scrubber size 27/66	425 (15,000)	N/A	7.5-11.3 (120-180)(3)	-	N/A
Proportioning area burden tunnel scrubber	Ducon VVO venturi scrubber size 24/60	340 (12,000)	N/A	6.2-9.3 (100-150)(3)	-	N/A
Burden bin scrubbers (three, one per burden bin)	AAF Size 3 Type R Rotoclone wet centrifugal collector	368 (13,000)	98(3)	2.8 (45)(3)	-	15 (6)(3)

(1) Information obtained from Tennessee Department of Public Health - Bureau of Environment and from data presented to SAI staff at October 14-15, 1982, meeting at Occidental Chemical plant in Columbia, Tennessee.

(2) Information not available (N/A).

(3) Estimated based on vendor literature.

undergoes further crushing and grinding operations after cooling. The ferrophosphorus is first crushed in a jaw crusher utilizing a water spray for suppression of dust generated. Although not used since 1977, a ball mill grinding system can be used for further sizing. This system has two baghouses for collecting of mill dust and product dust. Detailed design data for the taphole fume and ferrophosphorus processing system emission control equipment are summarized in Table 4-50.

Offgas Filtration Operations

The offgases from each furnace are drawn off by large vacuum pumps before proceeding on to the condensers. Each furnace has two spray tower condensers in series in which the product phosphorus condenses. The CO is then either recycled to the rotary kiln as a fuel or flared to atmosphere. The condensed phosphorus is collected in sumps and stored. Emissions at the #2 and #3 furnace sumps are controlled by a single American Air Filter (AAF) Kinpactor venturi-type scrubber with a cyclonic separator (see Appendix B for detailed technical information). Airborne emissions associated with phosphorus sludge evaporators and condenser sumps at the #1 furnace are also controlled by an AAF Kinpactor venturi with a cyclonic separator. In addition, similar scrubbing systems are used at the phosphorus sludge recovery tank, phosphorus filter area, and the phosphorus loading area. Phosphorus from the product storage tanks is filtered with carbon and stored before being sent to a loading area where it is loaded into railcars for shipment. Detailed design data for the offgas filtration operations are summarized in Table 4-51.

Fugitive Emissions Sources

The fugitive emission sources at the Occidental Chemical plant were identified and discussed in Chapter 3. Fugitive dust emissions from plant roads are controlled by using a water truck.

4.3.8.2 Costs

The costs for the emission control techniques and equipment used by the Occidental Chemical plant are based on data furnished by the company. Table 4-52 summarizes the capital, operating, and maintenance costs for the specific major emission source areas. The individual system costs and the

Table 4-50. Occidental Chemical Furnace Operations Airborne Emission Control Equipment(1).

Emission Point	Mfr. & Model No.	Gas Flow ACMM (ACFM)	Efficiency (%)	Water Rate l/s (gpm)	Air to Cloth Ratio	ΔP cm (in) W.G.
#1, 2, 3 furnace taphole fume scrubbers (each)	Air Pollution Industries venturi scrubber	1416 (50,000)	N/A(2)	N/A	-	N/A
Ferrophosphorus ball mill - mill dust baghouse	Flex-Kleen model 84-UDC-80A	85 (3000)	99.9	-	3.75/1	N/A
Ferrophosphorus ball mill - product dust baghouse	Flex-Kleen model 84-UDC-176	170 (6000)	99.9	-	3.4/1	N/A

(1) Information from Tennessee Department of Public Health - Bureau of Environment and from data presented to SAI staff at October 14-15, 1982, meeting at Occidental Chemical plant in Columbia, Tennessee.

(2) Information not available (N/A).

Table 4-51. Occidental Chemical Offgas Filtration Operations Scrubbers[1].

Emission Point	Mfr. & Model No.	Gas Flow ACMM (ACFM)	Efficiency (%)	Water Rate l/s (gpm)	ΔP cm (in) W.G.
#1 furnace offgas condensers (two)	Spray towers	N/A[2]	N/A	N/A	N/A
#2, 3 furnace offgas condensers (two per furnace)	Spray towers	N/A	N/A	N/A	N/A
#1 furnace evaporator and condenser sump scrubber	AAF size 8 Kinpactor venturi scrubber with size 115 cyclonic separator	227 (8000)	99.5[3]	3.1-6.2 (50-100)[3]	114 (45)
#2, 3 furnace sumps scrubber	AAF size 2 Kinpactor venturi scrubber with size 30 cyclonic separator	57 (2000)	N/A	0.75-1.5 (12-24)[3]	N/A
Phosphorus sludge recovery scrubber	AAF size 2 Kinpactor venturi scrubber with size 30 cyclonic separator	57 (2000)	N/A	0.75-1.5 (12-24)[3]	N/A
Phosphorus filter scrubber	AAF size 2 Kinpactor venturi scrubber with size 30 cyclonic separator	57 (2000)	N/A	0.75-1.5 (12-24)[3]	N/A
Phosphorus loading scrubber	AAF size 2 Kinpactor venturi scrubber with size 30 cyclonic separator	57 (2000)	N/A	0.75-1.5 (12-24)[3]	N/A

(1) Information obtained from Tennessee Department of PUblic Health - Bureau of Environment and from data presented to SAI staff at October 14-15, 1982, meeting at Occidental Chemical plant in Columbia, Tennessee.

(2) Information not available (N/A).

(3) Estimated based on vendor literature.

Table 4-52. Occidental Chemical Estimated Airborne Emission Control Equipment Costs in 1983 Dollars.

Emission Source	Control Equipment	Auxiliary Equipment	Capital[1,2] Cost	Annual[2] Operating Cost	Annual[2] Maintenance Cost
#4 rotary kiln system	Cyclones (eight), jet venturi scrubbers (four), separator tanks (two), lime bin baghouse	Fans, pumps, stacks	576,300	103,000	68,500
#1 rotary kiln system (inactive)	Cyclones (two), spray tower scrubber	Fan, pump	167,400	30,000	20,000
Nodule cooling and sizing system	Jet venturi scrubbers (four), spray tower scrubber, American Air Filter Rotoclone	Hoods, pumps, fans, stacks	332,400	59,200	30,500
Feed proportioning system	Coke fines hopper baghouse, lime storage tank baghouse, coke dryer venturi scrubber	Fans, pumps, hoods,	313,700	55,900	37,400
Burdening system	Venturi scrubber, American Air Filter Rotoclones (three)	Fans, pumps, stacks	127,700	22,800	15,200
#1 furnace off-gas system	Water spray condensers (two)	Fans, tanks, pumps, stack	409,000	73,000	49,000
#2 furnace off-gas system	Water spray condensers (two)	Fans, tanks, pumps, stack	183,000	33,000	22,000
#3 furnace off-gas system	Water spray condensers (two)	Fans, tanks, pumps, stack	215,000	38,700	25,800
#2 and #3 furnace sumps	American Air Filter Kinpactor venturi scrubber, cyclonic separator	Pump, fan, stack	39,000	7,000	4,600

Table 4-52. Occidental Chemical Estimated Airborne Emission Control Equipment Costs in 1983 Dollars. (Continued)

Emission Source	Control Equipment	Auxiliary Equipment	Capital[1,2] Cost	Annual[2] Operating Cost	Annual[2] Maintenance Cost
#1 furnace tapping system	Air Pollution Industries venturi scrubber, cyclonic separator	Hoods, fan, pump, stack	345,800	61,700	41,100
#2 furnace tapping system	Air Pollution Industries venturi scrubber, cyclonic separator	Hoods, fan, pump, stack	286,000	51,000	34,000
#3 furnace tapping system	Air Pollution Industries venturi scrubber, cyclonic separator	Hoods, fan, pump, stack	401,000	71,600	47,700
Ferrophosphorus processing system	Product dust baghouses (two)	Fans, stacks	53,800	9,400	6,500
P_4 filtration system	American Air Filter Kinpactor venturi scrubbers (four), cyclonic separators (four)	Fans, pumps, stacks	243,500	43,500	29,000
		Plant totals	3,693,600	659,800	440,300

(1) Capital costs adjusted to 1983 dollars based on Chemical Engineering Plant Cost Index [5].

(2) Estimate methodology presented in Ref. [6] and adjusted to 1983 dollars.

total operating and maintenance costs were provided by Occidental Chemical. All other individual costs were developed using the methodology presented in Ref. [6] and adjusted to 1983 dollars.

4.4 FACTORS AFFECTING EFFECTIVENESS OF AIRBORNE EMISSION CONTROL TECHNIQUES AND EQUIPMENT

4.4.1 General Selection Factors

Dust collection equipment is available in numerous designs using a number of principles that offer wide variations in effectiveness, initial cost, operating and maintenance costs, space, arrangement and materials of construction. Factors influencing equipment selection include:

- Concentration and particle size of contaminant
- Degrees of collection required
- Characteristics of air or gas stream
- Characteristics of contaminant
- Energy requirements
- Method of dust disposal

4.4.1.1 Concentration and Particle Size of Contaminant

Contaminants in offgas systems cover an extreme range in loadings and particle sizes. Concentrations can range from 0.1 to 20 or more grains per 0.0283 m^3 (1 ft^3) of gas. In low pressure conveying systems, usual dusts range from 0.5 to 100 or more microns. Deviation from mean size will also vary with the material. Smaller particulates require higher quality collectors. Respirable fines are particularly difficult to collect and require a high-efficiency collection (see Section 4.5).

4.4.1.2 Degree of Collection Required

The degree of collection (efficiency) required depends on the specific process and whether the cleaned gas will be recirculated or discharged. Other factors include plant location, quantity of escapement (mass rate of emission), the contaminant's potential as a health hazard or its ability to damage property, and governmental regulations. Generally, for a given concentration, the larger the offgas volume, the greater the need for better collection. Even though plants in remote locations might be considered to require lower degrees of collection, the potential damage to farms and the contribution to the pollution problems of cities must be considered.

Efficiency is closely linked to cost. Generally, electrostatic precipitators are highly efficient but are expensive; fabric or wet collectors are highly efficient but are in the moderate cost range; and dry centrifugal types are low cost and have low efficiencies. If high-efficiency collectors are required for a particular application, combination with primary (low-efficiency) collectors is usually considered.

4.4.1.3 Characteristics of Gas Stream

Gas streams exceeding approximately 82°C (180°F) preclude the use of low temperature media in fabric collectors. Condensing water vapor causes packing and plugging of gas or dust passages in dry collectors. Corrosive gases attack fabric or metal in dry collectors and when mixed with water in wet collectors can cause significant damage.

4.4.1.4 Characteristics of Contaminant

Certain chemicals in the contaminant could attack collector elements or cause corrosion in wet collectors. Sticky or linting materials could plug collector passages by adhering to certain types of collector surfaces or elements. Abrasive materials in moderate to heavy concentrations could cause rapid wear on dry metal surfaces. Particle size, shape, and density would rule out certain collector designs. Combustibility of finely-divided materials would influence selection of collectors.

4.4.1.5 Energy Requirements

Since electricity can account for as much as one-third of the production cost of phosphorus, the cost and availability of energy must be carefully considered for each collector type capable of achieving desired performance. Currently, energy costs are lowest for the northwest elemental phosphorus plants and highest for those plants in Florida.

4.4.1.6 Methods of Dust Disposal

Methods of removal and disposal of collected materials vary with the material, process, quantity involved, and collector design. Dry materials can be unloaded continuously or in batches through such devices as dump gates, trickle valves, or rotary valves to conveyers or containers. Dry materials can create a fugitive dust problem if careful thought is not given to disposal or to collector bin locations. Wet collectors can be arranged for batch removal or continual ejection of dewatered material by flight conveyers or draining as a slurry. Secondary dust problems are eliminated with wet collectors but disposal of wet sludge can be a material handling problem. Solids carried over in waste water can create a sewer or stream pollution problem if waste water is not properly clarified.

Material characteristics can influence disposal. Packing and bridging of dry materials in dust hoppers, floating or slurry forming characteristics in wet collectors are examples of problems that can be encountered.

4.4.2 Factors Affecting Specific Collectors

4.4.2.1 Cyclone Dust Collectors

Cyclones are generally used when particles of over 5 μm diameter are involved, although some multiple-tube parallel units attain 80 to 85 percent efficiencies on particles of 3 μm diameter. The most satisfactory expression for cyclone performance is the empirical relationship developed by Rosin, Rammler, and Intelmann [12]. They derived the following equation for determining the minimum diameter particle, $D_{p,min}$, that should be completely separated from the gas stream in a cyclone:

$$D_{p,min} = \left[\frac{9\mu B_c}{\pi N_{tc} V_c (\rho_s - \rho)}\right]^{0.5}$$

where μ = fluid viscosity, poise

B_c = width of rectangular cyclone inlet duct, cm

N_{tc} = number of turns made by a gas stream in a cyclone separator, dimensionless

V_c = cyclone inlet velocity, average, based on cyclone inlet area, cm/sec

ρ_s = true density (not bulk) of solids, g/cc

ρ = fluid density, g/cc

For a given inlet velocity, increased temperature will result in a larger cut size (diameter of particles of which half of those present are collected), corresponding to a lower efficiency. Because of counterbalancing effects of offgas density and viscosity, a given size cyclone will have approximately the same collection efficiency at any temperature, provided that the pressure drop is the same. Cyclones are usually designed to meet specific pressure drop limitations.

Collection efficiency can be changed relatively little by varying operating conditions. The primary design factor controlling efficiency is the cyclone diameter, with a smaller diameter unit operating at a fixed pressure drop having a higher efficiency. To achieve a specified capacity, however, multiple small-diameter units in parallel may be required. In such instances, the individual cyclones would typically discharge dust to a common receiving hopper. It is customary to design a single cyclone for a given capacity, resorting to multiple units in parallel only if the required collection efficiency cannot be achieved by a single unit.

Reducing the gas outlet duct diameter will increase both collection efficiency and pressure drop. Increasing the length of a cyclone is generally considered to increase collection efficiency, but there are no reliable supporting data. There is also no reliable information on the effect of inlet proportions, although the Rosin, Rammler, and Intelmann relationship indicates that for a given cyclone inlet velocity the inlet width should be minimized. It is essential that the inlet transition be relatively gradual to avoid excess pressure drop due to gas jetting into the cyclone chamber. Most cyclones have cone lengths equal to 1.6 to 3.0 cyclone diameters.

A cyclone will operate equally well on the suction or pressure side of a fan if the dust receiver is airtight. Probably the greatest single cause for poor cyclone performance, however, is the leakage of air into the dust outlet of the cyclone. A slight air leak at this point can result in a tremendous drop in collection efficiency, particularly with fine dusts.

A cyclone will operate as well in a horizontal position as in a vertical position. However, departure from the normal vertical position increases the tendency to plug the dust outlet, reducing collection efficiency. If the cyclone exit duct must be reduced to tie in with proposed duct sizes, the transition should be made downstream at a distance equal to at least five cyclone diameters and preferably after a bend.

Increased dust loadings decrease pressure drop and increase collection efficiency. At dust loadings of over 200 grains per 0.0283 cubic meter (cubic foot), the pressure drop may be as low as half that calculated in the absence of dust.

4.4.2.2 Electrostatic Precipitators

The performance of an electrostatic precipitator is affected by particle concentration and size distribution, the electrical resistivity and cohesivity of the layer of collected particles, and the uniformity of the gas flow.

The mechanism by which dust particles are electrically charged depends on the particle size, in addition to other factors such as the magnitude of the electric field and ion density. Large particles (larger than a few microns in diameter) are charged by the impact of gas ions travelling along electric field lines, and the charging ceases when the particle reaches a saturation charge that provides a sufficient repelling force. For normal operating currents, the saturation charge is reached within a fraction of a second. Small particles are charged more slowly, at a rate dependent on diffusion of the gas ions to the vicinity of the particle.

The electric field in a precipitator is determined by the geometry of the electrode system (the corona field being high near the corona electrode and diminishing with distance toward the collection electrode) and the space charge in the interelectrode region. The magnitude of the space charge is established by the number of elemental charges in this region. Both gas ions and charged particles contribute to the charge.

The collection efficiency also depends on the particle size. Collection efficiency is lowest for particles 0.5 to 1 μm in diameter, which can be explained in terms of the relative contributions of particle charging by different processes. The collection efficiency may increase for particle sizes smaller than 0.3 μm in diameter.

The collection efficiency is also influenced by the electrical resistivity of the dust. The electrical current from the corona discharge passes through the layer of dust deposited on the collection electrode, and the voltage drop across the layer depends on the resistivity of the dust, the current density, and the thickness of the layer. If the resistance of the dust layer is too high, the electric field in the layer can become high enough to exceed the field strength for electrical breakdown or corona discharge. These occurrences limit the voltage and current that can be used, and hence limit precipitator performance. The electrical resistivity of the dust depends principally on its chemical composition, the gas composition, and the temperature at which the precipitator operates.

The collection efficiency of an electrostatic precipitator can be degraded by losses during rapping of the collection electrodes. During this process, particles may be entrained in the gas stream. Such losses are moderated by dust cohesivity, but entrainment can be responsible for half of the total emissions from a precipitator. Losses and degraded performance can also occur because of uneven gas flow distribution and when particles pass through the nonelectrified space around the electrodes.

4.4.2.3 Fabric Filters

A heavy nonwoven (filter) fabric is more efficient than a woven fabric because the void areas or pores in the felted fabric are smaller. Any given fabric can be made more efficient by using smaller fiber diameters, a greater weight of fiber per fabric area, and weaving or packing more tightly. But as efficiency is increased by these means, the cleanability and permeability are reduced. A highly efficient fabric that cannot be cleaned offers an excessive resistance to gas flow and is not economic.

To compromise on fabric with better cleanability or greater permeability but lower inherent efficiency is not as detrimental as it may seem. Fabric efficiency is really meaningful only when new fabric is first put into service. After a short time, usually a matter of minutes, a precoat is established in the fabric pores that increases collection efficiency substantially. Depending on the amount of particulates and the time interval between cleanings, virtually all filtration may be by the collected particulates (filter cake) instead of the fabric. For dry dusts, if the filter cake is deeper than about 0.15 cm (about 0.5 kg/m^2 cloth), the overall pressure drop will usually be primarily due to the dust layer, with the drop due to the cloth, including the dust in the pores, being comparatively negligible. Even immediately after cleaning, a residual and/or redeposited dust cake provides additional filtration surface and a higher collection efficiency than obtainable with new fabric. Thus, the collection efficiency of new, clean fabric (easily determined by laboratory test and often published) does not represent operating conditions and is of little importance in selecting the proper collector. Fabric collector inefficiency normally results from bypass due to damaged fabric, faulty seals, or sheet metal leaks and not from fabric penetration.

Unless the gas moving device compensates for increased resistance as the filter cake increases, the gas volume flow rate will be reduced. Figure 4-13 shows how efficiency, resistance to flow, and flow rate change with time as the filter cake accumulates. Fabric collectors are designed and intended for relatively heavy dust concentrations. Dust collected on a square meter of fabric may exceed 3 kg per hour. In virtually all applications, the filter cake accumulated over several hours will represent sufficient resistance to reduce gas flow to a rate below an acceptable minimum. In a well-designed fabric collector system, the fabric or filter mat is cleaned or reconditioned before flow loss becomes critical.

Efficiency of new filter fabrics generally ranges from 50 to 75 percent for submicron dust (0.5 μm median diameter). Overall efficiency will typically increase rapidly and exceed 99 percent. After a period of cyclic filtration and cleaning ranging from a few hours to a few days, the residual deposit will stabilize and thereafter efficiency will typically be about 99.9 percent during normal operating conditions. The collection efficiency for the submicron fraction of the dust is usually greater than 90 percent.

4.4.2.4 Wet Scrubbers

The type of wet scrubber used in a given application depends mainly on particle size, the collection efficiency desired, and the allowable pressure drop. Table 4-53 shows typical pressure drops and minimum particle sizes for which various types of scrubbers have a collection efficiency of at least 80 percent. This information shows that simpler types of low pressure drop scrubbers are suitable for coarse particles while submicron particles require high pressure drop scrubbers.

The simplest type of scrubber, a spray tower, uses spray nozzles that produce droplets that are allowed to settle through a rising gas

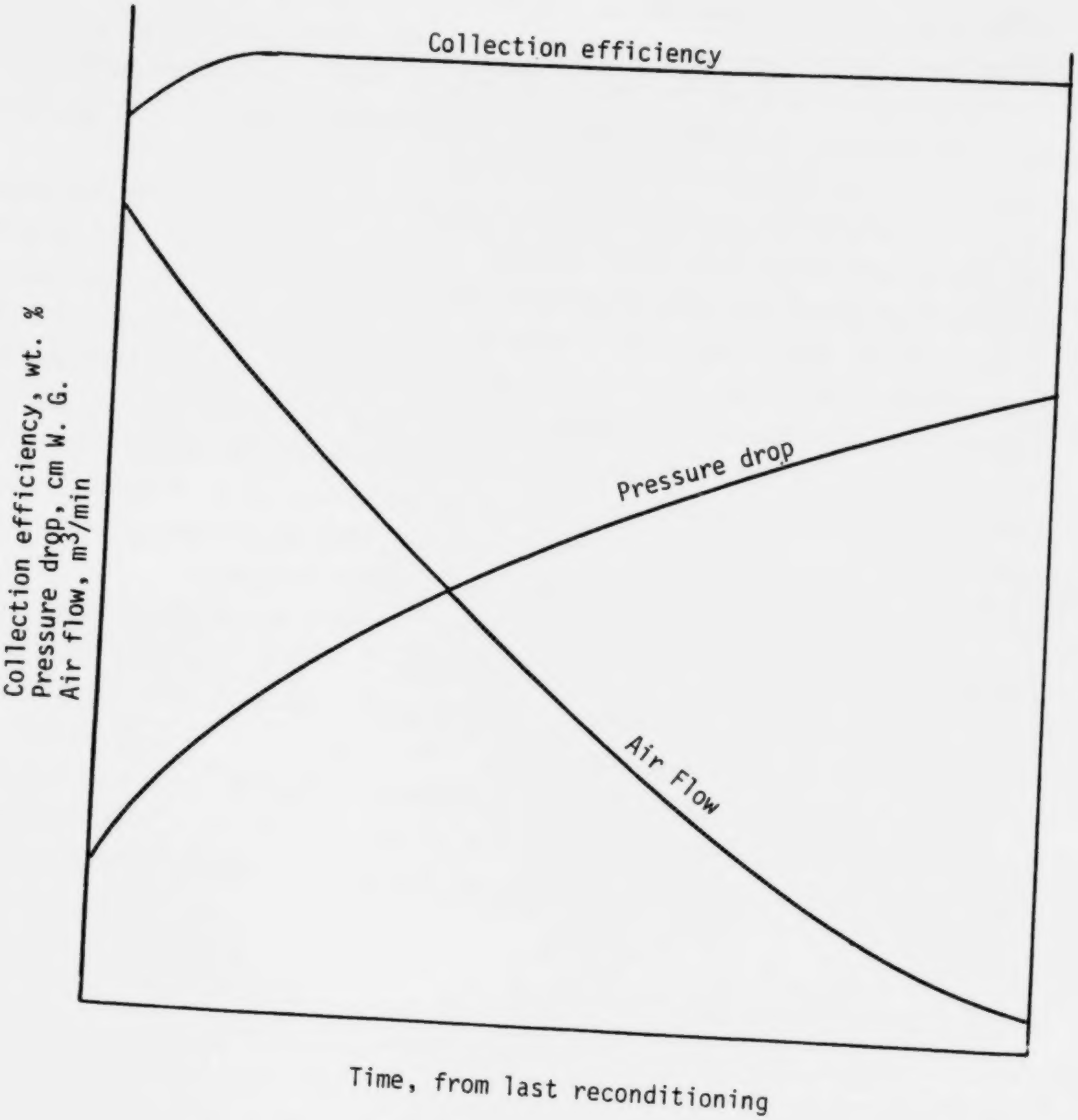


Figure 4-13. Fabric Filter Performance Versus Time Between Reconditioning.

Table 4-53. Minimum Particle Size for Various Types of Scrubbers.

Scrubber Type	Pressure Drop cm (in) W. G.	Minimum Particle Size (μm)
Spray Towers	1.3-3.8 (0.5-1.5)	10
Cyclone Spray Scrubbers	5-25 (2-10)	2-10
Impingement Scrubbers	5-127 (2-50)	1-5
Packed-bed Scrubbers	5-127 (2-50)	1-10
Venturi Scrubbers	13-254 (5-100)	0.8
Fiber-bed Scrubbers	13-280 (5-110)	0.5

stream. For optimum collection efficiency, the droplets should be in the range of 500 to 1000 μm in diameter. This would also ensure that most droplets would have a settling velocity greater than the upward velocity of the gas stream.

The collection efficiency of spray droplets in cyclone spray scrubbers can be increased by increasing the relative velocity between the dirty gas and the droplets. Cyclone spray scrubbers take advantage of the centrifugal force in a spinning gas stream with inertial impaction considered the controlling mechanism. The optimum droplet size for cyclone spray scrubbers is approximately 40 to 200 μm, considerably finer than that recommended for gravitational spray towers, with a corresponding increase in pressure drop (5 to 25 cm (2 to 10 in) W. G.).

Collection efficiency of venturi scrubbers depends on many variables, including particle size, gas velocity, spray liquid rate, and type of liquid injection. The basic scrubbing principle involves generating droplets from the scrubbing liquid. Droplets are created when the gas reaches maximum acceleration at the venturi throat region while impinging and shattering through a sheet of liquid. Smaller droplets are produced by increasing the acceleration. For effective collection, droplet diameters should be no larger than 200 times the particle diameter. The pressure drop required usually depends on such factors as particle size, particle size distribution, and the physical nature of the particles.

4.5 POTENTIAL APPLICATIONS OF ALTERNATIVE CONTROL TECHNIQUES AND EQUIPMENT

Fine particulates (3-5 μm or less) are known to be hazardous to health because they are not filtered out by the human respiratory system. Radioactive particulates are also thought to be in this size range. Control of respirable particulates with conventional technologies, however, is difficult because existing devices may not produce consistently high collection efficiencies and may not be cost effective with this particle size.

Of the major conventional technologies available, bag filters are probably the most effective with fine particles. These filters, however, have limited face velocity, limited capacity for loading, and high maintenance costs. Also, for a high-volume gas discharge, the filter area required is large, resulting in high capital and operating costs. For electrostatic precipitators, the cost-benefit ratio increases significantly with decreasing particle size and increasing particle resistivity. This is also true for wet scrubbing devices because high collection efficiency for submicron size particles is achieved at the expense of extremely high pressure drops and corresponding high costs.

Alternative emission control techniques that could be applied to the elemental phosphorus industry include improvements of existing methods and new technologies. In general, development has shifted toward improving conventional methods with some emphasis on combining methods. Examples of combinations are particle charging and electrostatic precipitation, electrostatics and fabric filtration, electrostatics and scrubbing, and electrostatics and cyclonic collection.

Much has been published on the potential improvements of existing devices, and these data will not be repeated here. The following relatively new technologies that might offer an improvement over conventional controls for a given emission source are discussed here.

- Electrified filter beds
- Agglomeration techniques
- New types of electrostatic precipitators

4.5.1 Electrified Filter Beds

Filtration by granular filters, which has been used for many years, has recently been modified by applying electric fields. Efficiency is increased by reducing the required residence time for collection. Also, the technique can be used with high temperatures and corrrosive emissions and requires less space than electrostatic precipitator or cloth bag filters. However, collected particulates and bed material may be re-entrained, and performance degrades with bed aging [13].

In a nonelectrified bed, particles are collected by inertial impaction, direct interception, or Brownian diffusion, depending on particle size. For particles of 1 µm or greater in diameter, inertia is most important; for those of 0.1 to 1 µm in diameter, direct interception is most important; and for very fine particles of approximately 0.1 µm or less in diameter, Brownian motion is the most important. The applicability of the various collection mechanisms to a particular aerosol depends upon the size distribution, the velocity and density of the particles with respect to the transport medium, and the susceptibility of the particles to external applied forces, such as electric fields, thermal gradients, or sonic energy. If an external field is applied, the collection efficiency may be increased due to the greater attraction of the filter media for the particles caused by the external field. The greater attraction allows shorter residence times for collection and corresponding reduction in bed size.

The electrified filter bed consists of a bed of fixed or movable granular particles (Figure 4-14), typically sand, clay, glass, or slate. The fluidized filter bed is one kind of electrified filter bed. Fluidization increases available surface area, maximizing collection efficiency, but decreasing residence times. Fluidization can, however, also cause operational problems and increased operational expense. The incoming particulates are generally charged by ion impact before entering the collection stages of the electrified filter bed. A prefilter is also used to collect the larger particles through inertia and impaction. An electrical field is applied across the bed and the induced charges on the semi-insulating particles attract incoming gas particles. Screens are often introduced into the collection column to prevent non-uniformity in the gas-solid distribution in a fluidized bed. Both the charging and collection sections of the electrified bed can be energized from common A-C, 60 Hertz power or by D-C.

When energized by A-C power, the electrified filter bed is considered to be a potential improvement over the D-C energized electrostatic precipitator which exhibits performance degradation due to the buildup of charges opposing the collecting field when the precipitator is exposed to high resistivity dust. The A-C field of the electrified filter bed should eliminate or greatly reduce such problems [14].

The system waste products are the bed materials and the collected particulates. Current configurations use hoppers or similar containers to collect and periodically remove the waste. The amount of media required depends on process emissions and the flow. Electrified filter beds have been successfully used with operations emitting oil ash and, on a pilot scale, with asphalt reprocessing operations and coal-fired boilers. Electrified filter beds have very high collection efficiencies for submicron particles, they do not foul as easily as a fabric filter or electrostatic precipitator for certain small particle sizes, and do not create the waste

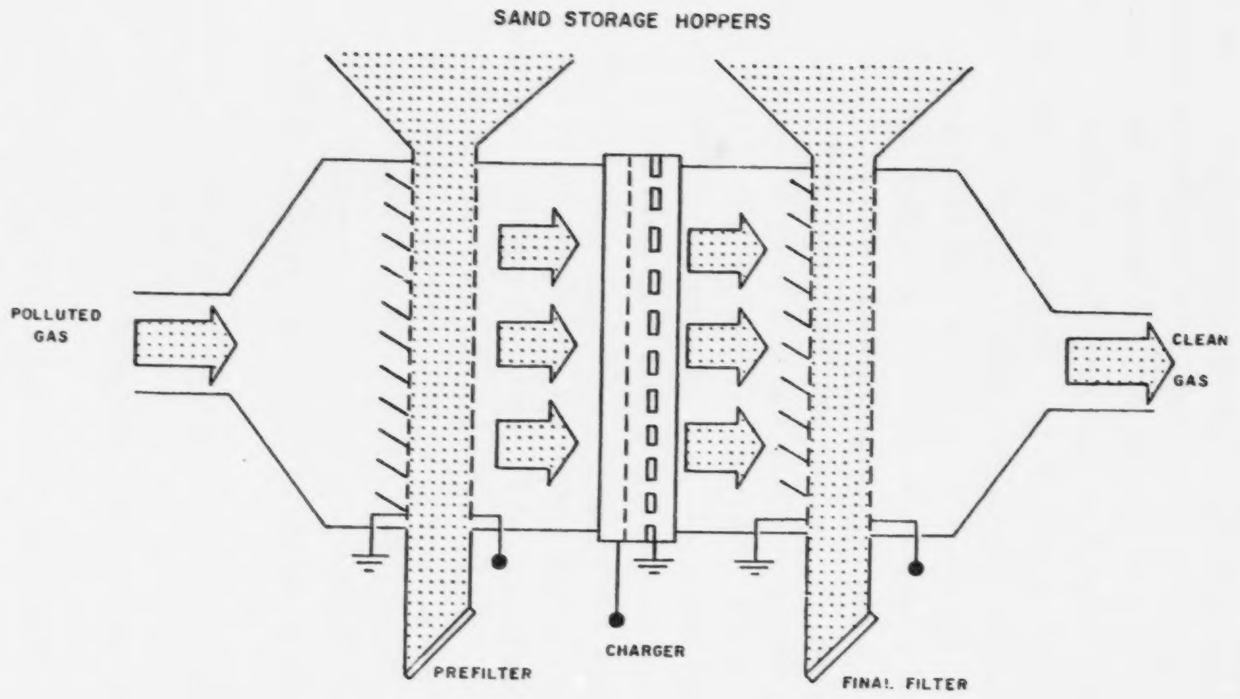

SAND STORAGE HOPPERS
POLLUTED GAS
CLEAN GAS
PREFILTER
CHARGER
FINAL FILTER

Figure 4-14. Schematic of the Electrified Bed Technology [13].

disposal problem of a wet collector such as a scrubber. The collected particulates can also occasionally be reused, which might have possible economic application to the elemental phosphorus industry.

4.5.2 Agglomeration Techniques

Since collecting respirable particulates is the most difficult and most energy consuming of all industrial particulate emissions, efforts have been made to develop systems that can improve the effectiveness of conventional control devices in capturing fine particles. One method is to cause agglomeration or growth of fine particles to simplify removal by existing controls. Several methods have been suggested to pre-condition particle-laden gases. Changing the particle size distribution could increase the efficiency of a downstream collector and reduce overall costs since collection devices generally retain a greater mass of a given aerosol as particle size is increased. Mechanisms that have been suggested as possible agglomeration inducers include thermal, turbulent, and acoustic agglomeration. As a group, their viability is questionable. At present, only acoustic agglomeration seems practical and economically feasible. Even so, the technology is still in the development stages and the cost and effectiveness of the techniques are uncertain. Since acoustic agglomerators are only dust-conditioning devices, efficiency and overall power requirements would depend on the downstream collector used. To significantly improve the collection of fine particles, the ratio of the final to initial mean particle diameter must be in the range of 5 to 20. The lower end of the range would require the use of a high-efficiency system as the collector (e.g., electrostatic precipitator, fabric filter, or venturi scrubber) while the upper end would allow the use of a low-efficiency system (e.g., cyclones) as the collector.

4.5.3 New Types of Electrostatic Precipitators

A number of new electrostatic precipitation techniques have been under recent investigation including:

- Trielectrode electrostatic precipitator
- Fluid electrode precipitator
- Wet-wall electroinertial unit

The trielectrode electrostatic precipitator is based on the concept that the layer of collected dust behaves like capacitance and resistance in parallel so that the corona will occur in short pulses and yet maintain a moderately constant current through the dust layer. Following each pulse, the voltage through the dust layer will decay exponentially with a time constant varying with the resistivity of the dust. Between corona pulses, a third electrode is kept at a high potential to provide a very strong field to drive the charged particles toward and deposit them on the collecting electrode.

The fluid electrode precipitator was designed in an attempt to alleviate problems that arise in the cleaning of conventional precipitators [15]. Built for continuous operation, this device is a conventional precipitator in which the collecting plates are replaced by columns of falling water. The dust-laden gas passes through a corona field generated between charged wires and grounded columns of water. Dust particles are charged and precipitated directly on the flowing water columns. The falling columns of grounded water act as cylinders in cross flow and create vortices for enhanced particle collection. Auxiliary electrodes and discharge electrodes can be positioned in arrays to direct charged dust into the grounded fluid. The water flows into a collecting tank and the clean gas passes into an exit duct.

The wet-wall electroinertial unit consists of a concentric wire-in-tube precipitator that combines inertial and electrostatic precipitating mechanisms and features continual washing of the collection surface [16]. The charging wire is located axially in a stainless steel tube in a vertical orientation. Air enters tangentially at the upper end of the tube (through a duct with a flattened cross section) and requires a rotating movement. When high voltage is applied to the wire, an ionizing corona charges the dust. As the air flows through the tube, the charged dust is driven to the wall by the radial electrical field. Water from an inlet at the upper end of the tube flows down the wall and flushes the precipitated dust into the water outlet at the lower end of the tube. The rotational movement of the air also induces rotational flow in the water, which assists in uniformly wetting the surface of the tube. Clean air is expelled from the lower end of the tube.

There is not much data available on the precipitation devices described. The wet-wall electroinertial unit and the fluid electrode precipitator seem capable of collection efficiencies of greater than 90 percent. However, these units were tested on fairly large diameter particulates. Experiments have successfully demonstrated the trielectrode electrostatic precipitator, showing collection efficiencies typically greater than 95 percent for high resistivity dust as compared with only 50 percent for a conventional precipitator.

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5.0 ANTICIPATED PROCESS ALTERATIONS

5.1 INTRODUCTION

This chapter discusses the likelihood that the domestic elemental phosphorus industry will undergo changes in operation in the foreseeable future. Specific examples of any changes due to expansion, modernization, or process alteration are identified along with effects on emissions that would result. Constraints that might prevent or limit the use of the emission control techniques and equipment discussed in the previous chapter are also identified.

5.2 ANTICIPATED CHANGES DUE TO INDUSTRY EXPANSION

In the past few years, the annual production of elemental phosphorus has declined because of changes in the economic condition of the United States as well as environmental concerns. These factors significantly impacted the major consumption areas of elemental phosphorus. The future of the elemental phosphorus industry remains sound in terms of availability of feed stock (phosphate rock) and in the continued requirement of elemental phosphorus in its pure state. The probability of industry expansion in the foreseeable future, however, is low. Economics, population growth, and environmental concern have worked against any increase in consumption.

With little or no expected increase in product demand and with continuing increases in costs of production, there is presently very little incentive for significant capital expenditure toward expansion or process alterations or improvements. None of the currently operating domestic plants has indicated any plans for such activity. Thus, future airborne emission levels resulting from existing production processes would probably not be significantly different unless emission control techniques and equipment or production rates were significantly changed.

5.3 ANTICIPATED CHANGES DUE TO MODERNIZATION

Several plants have indicated a continuing desire to improve various plant processes but have not done so because of the recent economic climate and state of the industry. Such improvements would not, however, substantially alter the basic production processes. Resulting changes would optimize or make operation or specific processes more efficient. Operators at only one plant indicated that they would like to modernize their emission control techniques and equipment if sufficient funds were available. In this instance, Andersen-2000 filter media systems were mentioned as the technique preferable to existing emission control techniques. No significant plant process modernization activities are planned for the forseeable future.

5.4 POTENTIAL PROCESS ALTERATIONS

Until the recently proposed Federal Clean Air Act standards, individual elemental phosphorus plants have not been required to comply with any radionuclide emission standards. They have only been required to comply with state particulate and fluoride emission standards. Since all plants normally operate in compliance with particulate emission standards, no significant operational changes or process alterations are currently planned. However, some plants have indicated that certain plant processes and/or emission control techniques could potentially be improved if economically justifiable. In addition, should existing standards be upgraded or new standards be established, process alterations could be required. One plant operator has stated that if standards were upgraded, the company would review the economics of the entire plant operation in relation to the cost of the required changes before deciding whether to continue plant operation.

Operators from several plants that use dry electrostatic precipitators for primary dust removal from furnace product offgases have indicated that this technique may not be the best available. For this application, dry electrostatic precipitators have been described as very high-maintenance equipment that does not accommodate spikes in dust loading very well and can pose safety hazards. A commonly used alternative technique would be traditional cyclone equipment and variations. The effect on airborne emissions associated with such an alteration would be small since the primary dust removal equipment is not used as an emission control.

Mobil Chemical has indicated that one potential process alteration would be an upgrading of its briquetting operation. The briquetting operation has experienced mechanical problems resulting in production of fewer briquettes than desired. The effect on airborne emissions associated with an upgrading of this sytem would be negligible. Mobil Chemical has also said that it might have installed Andersen-2000 filter media systems on certain processes had they been available when existing emission control equipment was installed.

FMC has indicated that they think the Andersen-2000 filter media system alone is adequate for furnace taphole fume control. Currently, two parallel Medusa scrubbers are used in series with an Andersen-2000 system for each furnace. If FMC were to rebuild these emission control systems, they would consider eliminating the Medusa scrubbers, which would probably decrease the airborne emission control efficiency of the overall system. However, the extent of this decrease would be such that FMC thinks it would still comply with existing particulate emission standards.

Occidental Chemical has indicated that if more stringent emission standards were adopted, certain scrubbers might require upgrading. The major example would be the addition of another venturi scrubber in series with each kiln venturi scrubber. This modification would significantly reduce airborne particulate emissions.

5.5 POTENTIAL CONSTRAINTS ON EXISTING OPERATION

Numerous studies of the supply of phosphate rock have been made, and the general conclusion is that the supply is adequate to meet demand for some time. Production of phosphate rock has increased steadily in the past 30 years, averaging about 6 percent per year [1]. This trend will probably continue into the foreseeable future, but the annual growth rate will decrease to approximately 2.2 percent through the year 2000. Within this time period, production from Tennessee is expected to terminate (1990), and production from the western states will probably increase slowly. Production from Florida will probably peak in the mid-1980s and decline after 1990. North Carolina should show a strong increase in production through the year 2000 [2]. Since a significant percentage of domestic elemental phosphorus production capacity is located in Tennessee, declining local ore production could affect producers' long range plans [3]. Changes in the sources of phosphate feed ores could significantly change feed material physical characteristics at a specific plant. In addition, radionuclide content in these feed materials could vary significantly. Thus, it is possible that changes in production processes or airborne emission control techniques would be required to maintain compliance with emission standards.

Another constraint that affects operation of the elemental phosphorus industry is the cost of electrical power. Power costs throughout the United States vary significantly, with costs in Florida being the highest and those in the northwest the lowest. Not only are costs of furnace operations significantly affected by electrical costs, but also by costs for operating emission control equipment, particularly for high-energy scrubbers. High power costs in Florida are the main reason both existing elemental phosphorus plants in that state are currently inactive.

Availability of electrical power is another consideration that can affect plant operation and performance of emission control equipment. At some plants, interruptions in power are commonplace and can affect the effectiveness of certain emission control systems. It is not uncommon for emissions from a specific system to exceed emission standards for short periods as a result of power interruptions.

5.6 REFERENCES

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2. Stowasser, W.F., "Phosphate-1977," in Mineral Commodity Profiles, Bureau of Mines, MCP-2, May 1977.

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6.0 MODEL ELEMENTAL PHOSPHORUS PLANT

6.1 INTRODUCTION

Based on information and data developed in previous chapters, parameters for a representative model elemental phosphorus plant were determined. The model plant is a parametric description of the type of plant representative of those operating now and likely to operate in the future. The geographical region chosen for the model plant is the Idaho-Montana area because of the currently higher combined production rate and capacity for plants in that region as compared to those in Tennessee. In addition, generally lower costs of operation and future ore availability considerations in the northwest make this area a suitable model plant location. The production capacity of the model plant is consistent with the larger plants in the industry.

6.2 MODEL PLANT SITE CHARACTERIZATION

The model elemental phosphorus plant is located in the northwestern United States in an area bounded by 110° to 113° longitude and 42° to 46° latitude. It is situated in a valley at an elevation of approximately 1600 meters. The plant is approximately 5 kilometers from the nearest city and within a kilometer of a main highway. In addition, a river or stream is located within a kilometer of the plant. The plant is serviced by a direct rail line which is the chief means for transport of major process materials.

The general area around the plant is mined for coal, copper and associated process feed materials. Fifty percent of the land is farmland of which 28 percent is used for rangeland. The primary agricultural products of the area are potatoes, food grains and beef cattle.

The population density of the region surrounding the plant is approximately 14 persons per square kilometer. Approximately 6000 people live within 5 kilometers of the plant. Those living closest to the plant are assumed to live 1.5 kilometers away.

Average rainfall in the region is 33 centimeters per year. Average air temperature is 8.5°C. Winds in the area of the plant are typically 4 to 10 knots from the south and west. Wind speed and frequencies for Pasquill categories are shown in Table 6-1. Site characteristic inputs for the AIRDOS-EPA code are listed in Table 6-2.

6.3 GENERAL PLANT DESCRIPTION

A simplified general process flow diagram for the model elemental phosphorus plant is presented in Figure 6-1. The model plant is assumed to operate two phosphate feed ore calciners, each of which is followed by a nodule cooler. Each of four elemental phosphorus furnaces has its own taphole fume treatment system. Offgases coming from each furnace are treated in separate electrostatic precipitators for dust removal and individual phosphorus condensers. Condensed phosphorus is sent through a filtration system for sludge removal prior to storage or shipment.

The major feed materials utilized by the model plant are characterized in Table 6-3. Chemical compositions and radionuclide contents shown are typical of materials found in the Idaho/Montana region of the United States. Estimated ranges of these values are ±10 percent. Because of cold winter weather, ore is normally shipped to the plant during the six-month summer season and stockpiled for eventual use during the winter months. The plant is assumed to operate 24 hours per day, 365 days per year. Feed material utilization shown in Table 6-3 is representative of plants currently operating in the region. Electrical power usage is approximately 13,000 kWh per short ton of elemental phosphorus produced, which is representative of plants in the region as well as other plants in the industry.

The major product materials produced by the model plant are characterized in Table 6-4. Chemical compositions and radionuclide contents shown are typical of materials produced at plants in the Idaho/Montana region of the United States. Production rates of slag and ferrophosphorus are also typical for operation of plants in this region. The ranges of the values shown in Table 6-4 are estimated to be ±10 percent.

Estimated annual costs for major raw materials utilized at the model elemental phosphorus plant are shown in Table 6-5. Current annual production rate of elemental phosphorus is assumed to be 120,000 short tons, which is representative of the larger northwestern plants. Estimated annual

Table 6-1. Averaged Wind Speeds and Frequencies for Pasquil Stability Categories A thorugh F for the Model Elemental Phosphorus Plant.

Direction	A		B		C		D		E		F	
	Freq.	Wind Speed m/s	Freq.	Wind Speed m/s	Freq.	Wind Speed m/s	Freq.	Wind Speed m/s	Freq.	Wind Speed m/s	Freq.	Wind Speed m/s
N	0.001	2.2	0.009	2.4	0.009	3.3	0.022	4.2	0.007	3.3	0.010	2.1
NNE	0.000	2.4	0.007	2.5	0.009	2.6	0.020	4.3	0.004	3.3	0.008	1.9
NE	0.001	1.8	0.007	2.4	0.008	3.2	0.017	3.7	0.006	3.1	0.009	2.0
ENE	0.000	2.5	0.004	2.6	0.004	3.1	0.008	4.2	0.004	3.2	0.005	1.8
E	0.000	2.4	0.003	2.2	0.003	3.1	0.008	4.0	0.004	3.1	0.007	2.0
ESE	0.001	2.3	0.003	2.2	0.003	3.4	0.009	4.8	0.002	2.8	0.006	2.0
SE	0.000	2.4	0.004	2.2	0.005	3.3	0.015	5.1	0.038	3.1	0.015	2.0
SSE	0.000	1.3	0.004	2.0	0.004	4.0	0.028	6.6	0.009	3.5	0.031	2.0
S	0.000	1.8	0.002	2.3	0.004	3.4	0.050	6.4	0.018	3.8	0.037	2.2
SSW	0.001	2.0	0.003	2.6	0.005	3.8	0.054	5.7	0.021	3.8	0.025	2.2
SW	0.001	2.2	0.003	2.5	0.008	4.0	0.079	6.3	0.013	3.6	0.016	2.1
WSW	0.001	2.2	0.003	2.6	0.011	4.9	0.072	7.3	0.005	3.6	0.007	2.0
W	0.001	2.3	0.004	2.8	0.008	4.7	0.033	6.6	0.004	3.4	0.006	1.9
WNW	0.001	1.9	0.005	2.7	0.007	4.3	0.035	6.1	0.005	3.5	0.007	2.0
NW	0.001	2.3	0.006	2.5	0.008	3.7	0.035	5.1	0.007	3.3	0.010	2.1
NNW	0.001	2.4	0.006	2.6	0.008	3.6	0.057	4.4	0.006	3.4	0.009	2.0

Table 6-2. Site Characteristic Input for the AIRDOS-EPA Code.

Characteristic	Code Name	Value
Rainfall rate (cm/yr)	RR	33
Height of lid a.m. (in) p.m. (in)	LIDAI	380 1930
Scavenging coefficient (sec^{-1})	SC	$3.3x10^{-7}$
Number of meat animals	NOBCT	22490
Number of dairy cows	NOMCT	1141
County size (m^2)		$3.4x10^9$
Area of produce production (m^2)	INTFC	0
Agricultural productivity of cattle feed (kg/m^2)	YSUBV1	1.5
Agricultural productivity of produce/leafy vegetables (kg/m^2)	YSUBV2	0

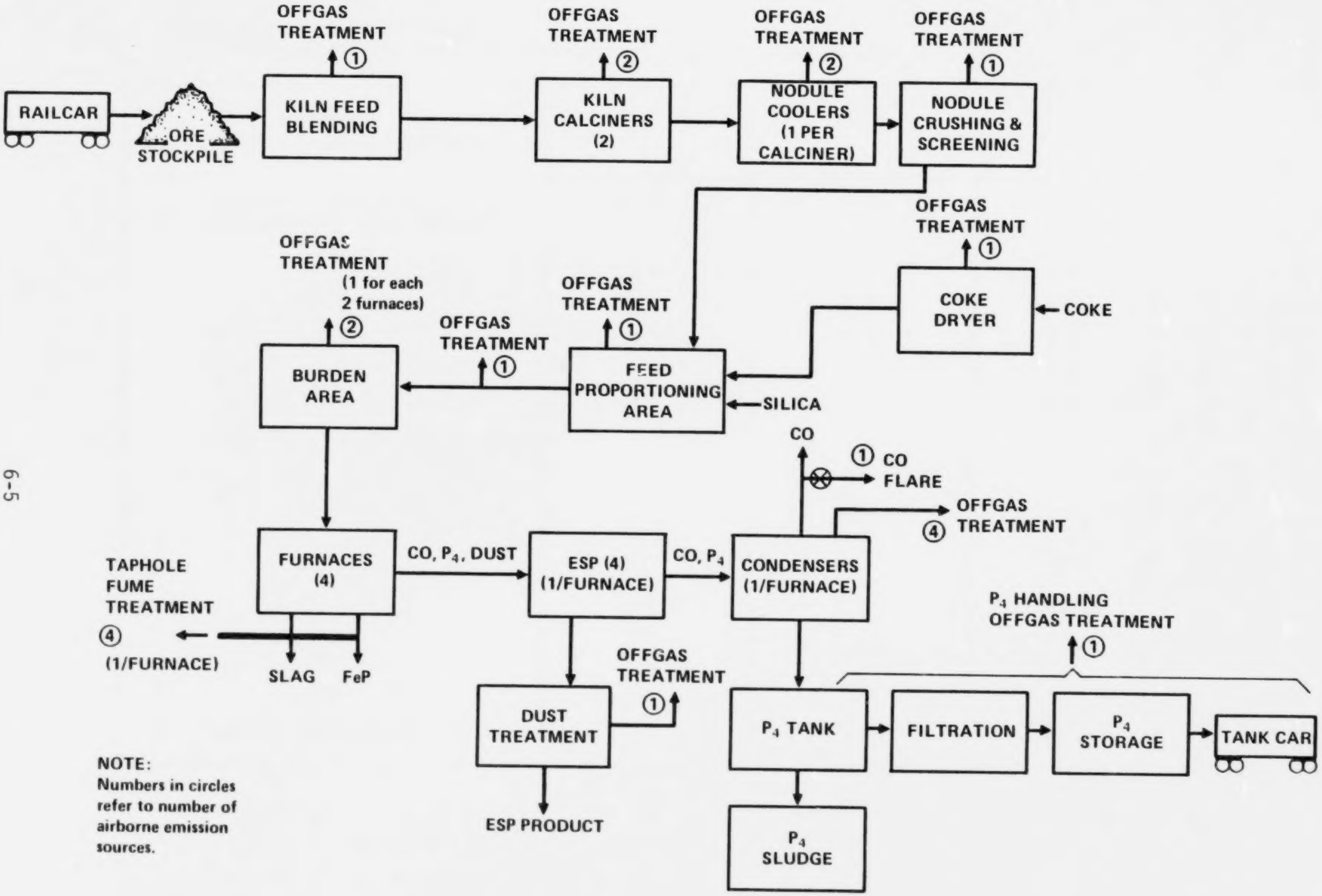
RAILCAR
ORE STOCKPILE
OFFGAS TREATMENT ①
KILN FEED BLENDING
OFFGAS TREATMENT ②
KILN CALCINERS (2)
OFFGAS TREATMENT ②
NODULE COOLERS (1 PER CALCINER)
OFFGAS TREATMENT ①
NODULE CRUSHING & SCREENING
OFFGAS TREATMENT ①
COKE DRYER
COKE
OFFGAS TREATMENT (1 for each 2 furnaces) ②
BURDEN AREA
OFFGAS TREATMENT ①
OFFGAS TREATMENT ①
FEED PROPORTIONING AREA
SILICA
CO
① CO FLARE
OFFGAS TREATMENT ④
TAPHOLE FUME TREATMENT
④ (1/FURNACE)
FURNACES (4)
SLAG
FeP
CO, P4, DUST
ESP (4) (1/FURNACE)
CO, P4
CONDENSERS (1/FURNACE)
P4 HANDLING OFFGAS TREATMENT ①
OFFGAS TREATMENT ①
DUST TREATMENT
ESP PRODUCT
P4 TANK
FILTRATION
P4 STORAGE
TANK CAR
P4 SLUDGE
NOTE:
Numbers in circles refer to number of airborne emission sources.

Figure 6-1. Simplified Process Flow Diagram - Model Plant.

Table 6-3. Model Plant Feed Materials Characterization.

	Phosphate Ore	Coke	Silica
1. Chemical Composition, wt %		-	-
P_2O_5	27.0	-	-
SiO_2	24.0	3.3	96.5
CaO	34.0	-	0.25
Al_2O_3	4.0	1.3	1.5
Fe_2O_3	1.7	0.3	1.0
C	2.0	90.5 (dry basis)	-
2. Radionuclide Content(1), pCi/g			
U-238	25.0	0.5	1.3
Th-230	25.0	0.2	1.4
Ra-226	25.0	0.7	1.5
Pb-210	25.0	2.2	0.7
Po-210	25.0	1.2	2.6
3. Feed Material Utilization, ton/ton P_4 produced	11.8	1.35	1.6
4. Electrical Power, kWh/short ton P_4 produced	13,000		

(1) Concentrations assumed the same for all radionuclides in the uranium-238 decay series.

Table 6-4. Model Plant Product Materials Characterization.

	Phosphorus	Slag	Ferrophosphorus
1. Chemical Composition, wt %			
SiO_2	-	42.5	-
CaO	-	44	-
Al_2O_3	-	6	-
Fe_2O_3	-	0.4	-
P_2O_5	-	1.4	-
P	>99.9	-	27.5
Fe	-	-	56
V	-	-	6.5
Cr	-	-	5.8
2. Radionuclide Content, pCi/g			
U-238	-	15	15
Th-230	-	35	0.4
Ra-226	0.02	31	0.3
Pb-210	0.25	5	0.9
Po-210	-	8	0.4
3. Production, ton/ton P_4 produced(1)	1.0	8.9	0.16

(1) Furnace ESP products produced at rate of 0.1 ton/ton P_4 produced.

Table 6-5. Model Plant Estimated Annual Raw Material Costs and Product and Byproduct Values in 1983 Dollars.

Material	Annual Process Rate (Short Tons x 10^3)	Estimated Unit Cost or Value (Dollars/short ton)	Estimated Annual Cost (Dollars x 10^6)	Estimated Annual Value (Dollars x 10^6)
Phosphate Ore	1415	23	32.55	
Coke	162	80	12.96	
Silica	192	14	2.69	
Lime	14	62	0.87	
Electrical Power	1.56×10^9 (kWh)	.025 ($/kWh)	39.0	
Auxiliary Plant Fuel	-	30 ($/ton P_4)	3.60	
Furnace Electrodes	-	55 ($/ton P_4)	6.60	
Phosphorus	120	1600(1)		192.0
Slag	1070	0.25		0.13(2)
Ferrophosphorus	19	140		2.66
ESP Product	12	17		0.21
Process Wastes	-	-		0.03

(1) Little or no profit

(2) Assumes half sold and half stockpiled

values of products and byproducts are also provided in Table 6-5. All estimated costs or values are presented as 1983 dollars. The remaining lifetime for the model plant is estimated to be 20 years without extensive expenditure for major equipment change or overhaul. Phosphate ore supply does not appear to be a limiting factor at this time.

6.4 AIRBORNE EMISSION SOURCE CHARACTERIZATION

Potential sources of airborne radionuclide emissions from the model plant are identified in Figure 6-1. However, very few of these can be considered to be major sources of Po-210 or Pb-210 airborne emissions. Application of at least a minimum level of emission control to potential major sources results in insignificant Po-210 and Pb-210 emissions from all but the calciner sources. The potential major sources are identified in Table 6-6 along with associated non-radiological stack characteristics. Stack data were developed by considering all elemental phosphorus plants in the northwestern United States and giving particular emphasis to the larger ones.

6.5 AIRBORNE EMISSION CONTROL TECHNIQUES

Three levels of emission control were defined for each of the major sources of airborne Po-210 and Pb-210 emissions associated with the model elemental phosphorus plant. The levels of control range from minimum to maximum application of control techniques and are generally representative of current industry practice. The control equipment systems specified for each level of control for each emission source are shown in Table 6-7. The estimated airborne particulate emissions from each major source are shown in Table 6-8. Efficiencies reported are total system efficiencies relating emissions released to the atmosphere and particulates generated by the specific plant process.

The estimated airborne radioactive emissions from each source at the model plant are given in Table 6-9 in curies per year. The high temperature of the calciners volatilizes the Po-210 and Pb-210 from the phosphate rock, resulting in the release of much greater quantities of the radionuclides than the uranium, thorium and radium radionuclides. Because of a lack of sufficient data, the Pb-210 emissions are assumed identical to those for Po-210 which are based primarily on available data [1,2]

Table 6-6. Model Plant Major Airborne Polonium and Lead Emission Sources.

Source	No. of Stacks[1]	Stack Geometry		Stack Gas Characteristics			
		Height (m)	Diameter (m)	Flow (ACMM)	Exit Velocity (m/s)	Exit Temperature °C (°K)	Heat Release (cal/s)
Calciner offgas	2	30	2.4	4400	16.2	60 (333)	9.9×10^5
Nodule cooler offgas	2	24	2.4	2500	9.2	47 (320)	4.1×10^5
Furnace taphole fume	4	30	1.15	1060	17.0	34 (307)	1.2×10^5

(1) Assumes stack parameters are identical for all stacks where more than one stack is indicated.

Table 6-7. Model Plant Airborne Emission Control Equipment for Major Polonium and Lead Sources.

Process	Emission Source	Type of Equipment		
		Minimum Control	Intermediate Control	Maximum Control
Calciner (two), each	Calciner offgas	Baffled settling chamber, spray tower scrubber	Multicyclone, spray tower scrubber	Multicyclone, spray tower scrubber, wet ESP
Calciner cooler (two), each	Nodule cooling operation	Spray tower scrubber	Multicyclone, spray tower scrubber	Multicyclone, venturi scrubber
Furnace taphole fume collection (four), each	Slag and ferrophosphorus tapping operations	Wet electrostatic precipitator (one per two furnaces)	Venturi scrubber	Venturi scrubber, high-efficiency filter media scrubber

Table 6-8. Model Plant Estimated Airborne Particulate Emissions from Major Airborne Radionuclide Sources.

Emission Source	Minimum Control		Intermediate Control		Maximum Control	
	Rate, kg/hr (g/sec)	Efficiency(1), %	Rate, kg/hr (g/sec)	Efficiency(1), %	Rate, kg/hr (g/sec)	Efficiency(1), %
Calciner (two), total	49 (13.6)	99.8	28 (7.7)	99.9	0.55 (0.15)	99.998
Calciner cooler (two), total	9.1 (2.5)	98.0	1.8 (0.5)	99.6	0.9 (0.25)	99.8
Furnace taphole fume collection (four), total	20 (5.6)	98.5	6.8 (1.9)	99.5	1.4 (0.38)	99.9

(1) Efficiency reported as overall efficiency for total system of emission control equipment at each source.

Table 6-9. Model Plant Estimated Airborne Radioactive Emissions in Curies per Year from Major Sources(1,2).

Emission Source	Minimum Control		Intermediate Control		Maximum Control	
	Po-210, Pb-210	U-238, U-234, Th-230, Ra-226	Po-210, Pb-210	U-238, U-234, Th-230, Ra-226	Po-210, Pb-210	U-238, U-234, Th-230, Ra-226
Calciner (two), total	7.1	6.5×10^{-3}	4.0	3.0×10^{-3}	0.63	6.0×10^{-5}
Calciner cooler (two), total	1.6×10^{-3}	9.6×10^{-4}	4.8×10^{-4}	2.0×10^{-4}	3.2×10^{-4}	1.0×10^{-4}
Furnace taphole fume collection (four), total	4.5×10^{-4}	2.2×10^{-3}	1.5×10^{-4}	7.5×10^{-4}	3.1×10^{-5}	1.5×10^{-4}

(1) Values for Pb-210 assumed identical to those for Po-210.

(2) Values for U-238, U-234, Th-230, and Ra-226 based on particulate emission rate data and assumed identical.

normalized to model plant process rates. The U-238, U-234, Th-230, and Ra-226 radionuclide emission rates are based on particulate emission rates (Table 6-8) and the specific activity of the emitted dust. The emission rates for these radionuclides are assumed identical because of insufficient radionuclide-specific data.

6.6 ESTIMATED EQUIPMENT COSTS

The estimated costs for each model plant control option are shown in Tables 6-10, 6-11, and 6-12. Capital, annual operating, and annual maintenance costs for equipment systems at each emission source are summarized. All costs are based on specified process rates and were developed on the basis of methodology presented in Ref. [3].

Table 6-10. Model Plant Estimated Airborne Emission Control Equipment Costs in 1983 Dollars for Minimum Level Control Options(1).

Emission Source	Control Equipment	Auxiliary Equipment	Capital Cost	Annual Operating Cost	Annual Maintenance Cost
Calciner (two), each	Baffled settling chambers (two per scrubber), spray tower scrubber (two)	Fans (two), scrubber pumps (two), stacks (two)	1,024,000	198,500	50,000
Calciner cooler (two), each	Spray tower scrubber (two)	Fans (two), scrubber pumps (two), stacks (two)	524,000	160,000	32,700
Furnace taphole fume collection (four), each)	Wet ESP (one per two furnaces)	Pumps (two), stacks (two)	4,750,000	160,200	73,400
		Plant Totals	6,298,000	518,700	156,100

(1) Estimate methodology presented in Ref. [3].

Table 6-11. Model Plant Estimated Airborne Emission Control Equipment Costs in 1983 Dollars for Intermediate Level Control Options(1).

Emission Source	Control Equipment	Auxiliary Equipment	Capital Cost	Annual Operating Cost	Annual Maintenance Cost
Calciner (two), each	Multicyclones (two), spray tower scrubbers (two)	Fans (two), pumps (two), stacks (two)	958,600	220,500	86,300
Calciner cooler (two), each	Multicyclones (two), spray tower scrubbers (two)	Fans (two), pumps (two), stacks (two)	691,000	159,000	62,200
Furnace taphole fume collection (four), each	Venturi scrubbers (four), cyclonic separators w/demister (four)	Fans (four), pumps (two), stacks (four)	1,407,000	251,000	167,000
		Plant Totals	3,056,600	630,500	315,500

(1) Estimate methodology presented in Ref. [3].

Table 6-12. Model Plant Estimated Airborne Emission Control Equipment Costs in 1983 Dollars for Maximum Level Control Options(1).

Emission Source	Control Equipment	Auxiliary Equipment	Capital Cost	Annual Operating Cost	Annual Maintenance Cost
Calciner (two), each	Multicylones (two), spray tower scrubbers (two), wet ESP (two)	Fans (two), pumps (four), stacks (two)	8,827,800	529,800	441,400
Calciner cooler (two), each	Multicyclones (two), venturi scrubbers (two)	Fans (two), pumps (two), stacks (two)	1,188,800	212,000	141,300
Furnace taphole fume collection (four), each	Venturi scrubbers (four), high-efficiency filter media scrubbers (four)	Fans (four), pumps (eight), stacks (four)	3,828,000	205,900	186,500
		Plant Totals	13,844,600	947,700	769,200

(1) Estimate methodology presented in Ref. [3].

6.7 REFERENCES

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APPENDIX A - NONPROCESS CODE INPUT DATA FOR AIRDOS/RADRISK

A.1 GENERAL INPUT PARAMETERS

Table A-1 lists miscellaneous terrestrial transport input parameters. Most of these parameters are described along with the assumptions used to determine them [A-1]. All estimates are conservative and tend to overestimate the resulting dose. The values for f_g, f_e (fraction of produce, leafy vegetables grown in garden of interest) and DDI (fraction of radioactivity retained on leafy vegetables and produce after washing) were very conservatively assumed to equal 1 [A-1], but 0.5 is recommended in Table A-1 as a more reasonable but still conservative number.

Table A-2 summarizes area specific code parameters. The code requires the use of an array input format for these data. Data are listed as total numbers for the county in which a plant is located. It is a reasonable assumption that no food animals or produce are closer than 400 m to the site and that a constant density distribution may be used beyond that distance. County census data provides the most localized data readily available. Agricultural productivity of cattle feed is the sum of cattle feed production census data of pasturage, grain, hay, and silage. Agricultural productivity of produce and leafy vegetables is the sum of the census data for leafy vegetable and exposed produce production but does not include data for protected produce or grain production. Protected produce will not be directly exposed to contaminant deposition and grains are usually subjected to processing and storage not accounted for in the code.

Table A-3 lists radionuclide-specific input parameters. Available data [A-1] for soil accumulation, plant uptake, and milk and meat transfer coefficients are element-specific rather than radionuclide-specific. No radionuclide-specific data is available, but while different isotopes will react at different rates in biosystems, the difference will not be of critical significance. The meat transfer data for P_o and R_a are based on studies conducted with sheep, caribou, and reindeer and may not be valid when used for beef cattle.

Table A-1. Miscellaneous Terrestrial Parameters.(1)

Parameter	Code Name	Value
Milk production(2)	USUBM	11.0 1/d
Muscle mass of beef	MSUBB	200 kg
Fraction of garden vegetables	FSUBG FSUBL	1.0
Time delay - pasture grass	TSUBHI	0 hr
Time delay - stored feed	TSUBH2	2160 hr
Time delay - leafy vegetables	TSUBH3	336 hr
Time delay - produce	TSUBHY	336 hr
Removal rate/weathering	LAMW	0.0021/hr
Exposure period - grass	TSUBE1	720 hr
Exposure period - vegetables	TSUBE2	1440 hr
Fraction of year grazing	FSUBP	0.4
Fraction of year - pasture	FSUBS	0.4
Consumption of contaminated feed	QSUBF	15.6 kg/day
Transport time: feed - man	TSUBF	2 day
Long-term buildup	TSUBB	100 years
Effective surface soil density	P	215 kg/m^2
Fallout interception - pasture	R1	0.57
Fallout interception - vegetable	R2	0.2
Produce ingestion by man	UV	176 kg/yr

Table A-1. Miscellaneous Terrestrial Parameters. (Continued)

Parameter	Code Name	Value
Milk ingestion by man	UM	112 l/year
Meat ingestion by man	UF	85 kg/year
Breathing rate of man(3)	BRTHRT	9.5×10^5 cm^3/hr
Fraction ingestion of local produce	RVEG	0.5
Fraction ingestion of local meat	RBEF	0.5
Fraction ingestion of local milk	RMLK	0.5
Fraction of herd slaughtered	TAUBEF	0.0038
Imported vegetables ingested	F3VEGM	0.20
Imported meat ingested	F3BEFM	0.20
Imported milk ingested	F3MLKM	0.20
Dilution factor for swimming	DILFAC	152 cm
Fraction of time swimming	USEFAC	0.01
Surface deposition	T	3.65×10^4 days
Radioactivity after washing	DD1	0.5

(1) Data from Ref. [A-1].

(2) Data from Ref. [A-2].

(3) Data from Ref. [A-3].

Table A-2. Miscellaneous Terrestrial Input Parameters by County.(1)

Parameter	Code Name	County					
		Power ID	Caribou ID	Silver Bow MT	Maury TN	Dunellas FL	Polk FL
Plant		FMC	Monsanto	Stauffer	Stauffer Occidental Monsanto	Stauffer	Mobil Chemical
No. of meat animals	NOBCT	18741	41932	6796	59965	1817	74189
No. of dairy cows	NOMCT	334	2900	188	7711	1280	6741
County size (m^2)		3.7×10^9	4.5×10^9	1.9×10^9	1.6×10^9	6.9×10^8	4.8×10^9
Area of produce production (m^2)	INTFC	0	0	0	9.44×10^4	0	7.85×10^5
Agricultural productivity of cattle feed (kg/m^2) in dry weight	YSUBV1	2.13	1.73	0.70	1.72	3.04	0.66
Agricultural productivity of produce/leafy vegetables (kg/m^2)	YSUBV2	0	0	0	2.57	0	2.92

(1) Data from Ref. [A-4].

Table A-3. Radionuclide-Specific Environmental and Miscellaneous Data.(1)

Parameter	Code Name	U	Th	Ra	Po	Pb	Bi
Soil bioaccumulation	BSUBV1	8.5×10^{-3}	2.7×10^{-3}	9.7×10^{-2}	4.2×10^{-3}	1.1×10^{-1}	
Plant uptake	BSUBV2	2.9×10^{-4}	3.5×10^{-4}	6.2×10^{-2}	2.6×10^{-4}	3.9×10^{-3}	
Milk transfer coefficient (days/1)	FSUBM1	1.2×10^{-4}	5.0×10^{-6}	5.9×10^{-4}	1.2×10^{-4}	9.9×10^{-5}	
Meat transfer coefficient (days/kg)	FSUBFI	1.6×10^{-6}	1.6×10^{-6}	5.0×10^{-4}	4.0×10^{-3}	9.1×10^{-4}	
Decay constant (day^{-1})	LAMRR	234: 7.77×10^{-9} 238: 4.25×10^{-13}	228: 9.93×10^{-4} 230: 2.47×10^{-8}	226: 1.19×10^{-6}	210: 5.02×10^{-3}	210: 8.52×10^{-5}	
Solubility class(2)	NNUCS	year	year	week	week	week	week
Environmental decay	LAMSUR	0	0	0	0	0	
Water decay constant	LAMH2O	0	0	0	0	0	
Dose conversion factors water/food	TDCF TDCF	0	0	0	0	0	
Deposition velocity (cm/sec)	VD	0.1	0.1	0.01	0.1	0.1	

(1) Data from Ref. [A-1].

(2) Data from Ref. [A-5].

Table A-4 contains state-specific meteorological input parameters. All data are as specific as possible for the region of the state in which the plant (or plants) is located. The scavenging coefficient (SC) has been approximated using the formula:

$$SC\ (\text{sec}^{-1}) = \text{rainfall rate (m/yr)} \times 10^{-5}$$

Tables A-5 through A-8 are STAR data (wind distribution by Pasquill stability classes) obtained from the closest reporting center to each plant. These tables contain the information for code input PERD, wind direction frequency; FRAW, Pasquill stability frequencies; and UDAV, the true-averaged wind speeds.

A.2 SITE-SPECIFIC INPUT PARAMETERS

Table A-9 lists site-specific population data for each of the elemental phosphorus plants. Data is listed as the number of persons living within a certain radius of the plant. Some of the population in the area of the Tennessee plants live within 20 km of 2 or 3 of the plants and have been included in the population distributions for each of the plants.

Table A-4. Meteorological Input Parameters.

Parameter	Code Name	Idaho	Tennessee	Montana	Florida
Rainfall rate(1) (cm/yr)	RR	31	140	38	187
Height of lid(2) a.m. (m) p.m. (m)	LIDAI	 350 1800	 500 1600	 450 2200	 700 1300
Scavenging coefficient (sec^{-1})	SC	3.0×10^{-7}	1.4×10^{-6}	3.8×10^{-7}	1.9×10^{-6}

(1) Data from Ref. [A-6].

(2) Data from Ref. [A-7, A-8].

Table A-5. Wind Distribution - Butte, MT(1)

ANNUAL FREQUENCY DISTRIBUTIONS - ALL STABILITY CLASSES   STATION =24135 BUTTE, MONTANA 56-60 0 UDS

	SPEED(KTS)					
DIRECTION	0 - 3	4 - 6	7 - 10	11 - 16	17 - 21	GREATER THAN 21	TOTAL
N	0.024518	0.017989	0.013095	0.004756	0.002137	0.000138	0.062633
NNE	0.018566	0.010821	0.008409	0.002206	0.000207	0.000138	0.040345
NE	0.012518	0.006892	0.002688	0.000414	0.000000	0.000000	0.022512
ENE	0.006343	0.003308	0.002206	0.000689	0.000276	0.000000	0.012821
E	0.006245	0.004273	0.001861	0.001378	0.000138	0.000069	0.013965
ESE	0.010210	0.005514	0.005238	0.005100	0.001516	0.000689	0.028267
SE	0.028914	0.016955	0.009236	0.009580	0.002619	0.000482	0.067786
SSE	0.052193	0.028810	0.020608	0.013371	0.002895	0.000482	0.118358
S	0.047604	0.035151	0.016610	0.006617	0.002412	0.000620	0.109214
SSW	0.033079	0.020815	0.016266	0.008546	0.002688	0.000414	0.081807
SW	0.019593	0.012613	0.011441	0.010201	0.003722	0.000689	0.058259
WSW	0.011227	0.007099	0.016197	0.018747	0.006892	0.001034	0.061196
W	0.010714	0.006961	0.012475	0.007926	0.002068	0.000345	0.040489
WNW	0.019485	0.013371	0.025019	0.024330	0.007099	0.002757	0.092061
NW	0.024972	0.017644	0.028603	0.021049	0.005858	0.001585	0.100511
NNW	0.028504	0.020401	0.024812	0.013026	0.002550	0.000482	0.089776
TOTAL	0.354883	0.228616	0.214763	0.148735	0.043077	0.009925	

TOTAL RELATIVE FREQUENCY OF OBSERVATIONS = 1.000000

TOTAL RELATIVE FREQUENCY OF CALMS DISTRIBUTED ABOVE = 0.212627

(1) Data from Ref. [9].

Table A-5 (Continued).

ANNUAL FREQUENCY DISTRIBUTIONS - STABILITY CLASS F   STATION =24135 BUTTE, MONTANA 56-60 8 OBS

DIRECTION	SPEED(KTS) 0 - 3	4 - 6	7 - 10	11 - 16	17 - 21	GREATER THAN 21	TOTAL
N	0.007018	0.002481	0.000000	0.000000	0.000000	0.000000	0.009499
NNE	0.005581	0.001172	0.000000	0.000000	0.000000	0.000000	0.006752
NE	0.004047	0.001103	0.000000	0.000000	0.000000	0.000000	0.005150
ENE	0.002059	0.000345	0.000000	0.000000	0.000000	0.000000	0.002403
E	0.002148	0.000827	0.000000	0.000000	0.000000	0.000000	0.002976
ESE	0.004366	0.001585	0.000000	0.000000	0.000000	0.000000	0.005951
SE	0.015725	0.006134	0.000000	0.000000	0.000000	0.000000	0.021859
SSE	0.039996	0.015852	0.000000	0.000000	0.000000	0.000000	0.055849
S	0.036218	0.022607	0.000000	0.000000	0.000000	0.000000	0.058824
SSW	0.023077	0.011028	0.000000	0.000000	0.000000	0.000000	0.034104
SW	0.011018	0.003860	0.000000	0.000000	0.000000	0.000000	0.014878
WSW	0.004985	0.001310	0.000000	0.000000	0.000000	0.000000	0.006294
W	0.004368	0.000896	0.000000	0.000000	0.000000	0.000000	0.005264
WNW	0.007612	0.002688	0.000000	0.000000	0.000000	0.000000	0.010300
NW	0.008753	0.003722	0.000000	0.000000	0.000000	0.000000	0.012474
NNW	0.009466	0.002550	0.000000	0.000000	0.000000	0.000000	0.012017
TOTAL	0.186436	0.078158	0.000000	0.000000	0.000000	0.000000	

RELATIVE FREQUENCY OF OCCURRENCE OF F STABILITY = 0.264594

RELATIVE FREQUENCY OF CALMS DISTRIBUTED ABOVE WITH F STABILITY = 0.105245

Table A-5 (Continued).

ANNUAL FREQUENCY DISTRIBUTIONS - STABILITY CLASS E   STATION #24135 BUTTE, MONTANA 56-60 H OBS

	SPEED(KTS)						
DIRECTION	0 - 3	4 - 6	7 - 10	11 - 16	17 - 21	GREATER THAN 21	TOTAL
N	0.000000	0.002895	0.001654	0.000000	0.000000	0.000000	0.004549
NNE	0.000000	0.001241	0.001034	0.000000	0.000000	0.000000	0.002274
NE	0.000000	0.000896	0.000138	0.000000	0.000000	0.000000	0.001034
ENE	0.000000	0.000345	0.000138	0.000000	0.000000	0.000000	0.000482
E	0.000000	0.000620	0.000276	0.000000	0.000000	0.000000	0.000896
ESE	0.000000	0.001103	0.000345	0.000000	0.000000	0.000000	0.001447
SE	0.000000	0.004342	0.002895	0.000000	0.000000	0.000000	0.007237
SSE	0.000000	0.006479	0.007719	0.000000	0.000000	0.000000	0.014198
S	0.000000	0.007030	0.009511	0.000000	0.000000	0.000000	0.016541
SSW	0.000000	0.004687	0.006479	0.000000	0.000000	0.000000	0.011165
SW	0.000000	0.003170	0.002274	0.000000	0.000000	0.000000	0.005445
WSW	0.000000	0.001723	0.002274	0.000000	0.000000	0.000000	0.003998
W	0.000000	0.001792	0.001861	0.000000	0.000000	0.000000	0.003653
WNW	0.000000	0.002757	0.004894	0.000000	0.000000	0.000000	0.007650
NW	0.000000	0.003653	0.005031	0.000000	0.000000	0.000000	0.008684
NNW	0.000000	0.003791	0.003722	0.000000	0.000000	0.000000	0.007513
TOTAL	0.000000	0.046523	0.050245	0.000000	0.000000	0.000000	

RELATIVE FREQUENCY OF OCCURRENCE OF E STABILITY = 0.096767

RELATIVE FREQUENCY OF CALMS DISTRIBUTED ABOVE WITH E STABILITY = 0.000000

Table A-5 (Continued).

ANNUAL FREQUENCY DISTRIBUTIONS - STABILITY CLASS D STATION #24135 BUTTE, MONTANA 56-60 8 OBS

	SPEED(KTS)						
DIRECTION	0 - 3	4 - 6	7 - 10	11 - 16	17 - 21	GREATER THAN 21	TOTAL
N	0.006086	0.006617	0.008340	0.004687	0.002137	0.000138	0.028003
NNE	0.005022	0.004825	0.005445	0.002068	0.000207	0.000138	0.017704
NE	0.002344	0.001792	0.001310	0.000345	0.000000	0.000000	0.005790
ENE	0.001103	0.000965	0.000896	0.000689	0.000276	0.000000	0.003929
E	0.001349	0.001310	0.001172	0.001310	0.000138	0.000069	0.005347
ESE	0.002009	0.001241	0.003033	0.004825	0.001516	0.000689	0.013312
SE	0.004303	0.003377	0.003653	0.008891	0.002481	0.000414	0.023119
SSE	0.004550	0.004411	0.010614	0.012889	0.002895	0.000482	0.035840
S	0.005101	0.003860	0.006479	0.006341	0.002343	0.000620	0.024744
SSW	0.004776	0.003791	0.007650	0.008271	0.002619	0.000414	0.027520
SW	0.004234	0.004135	0.007168	0.009511	0.003722	0.000689	0.029460
WSW	0.002826	0.002608	0.011717	0.018127	0.006617	0.001034	0.043008
W	0.003004	0.003102	0.008340	0.007719	0.001999	0.000345	0.024507
WNW	0.005416	0.005514	0.016541	0.023296	0.006961	0.002688	0.060417
NW	0.007090	0.006892	0.018747	0.021159	0.005790	0.001585	0.061264
NNW	0.008883	0.009236	0.016128	0.012544	0.002481	0.000482	0.049754
TOTAL	0.068096	0.063753	0.127231	0.142670	0.042181	0.009787	

RELATIVE FREQUENCY OF OCCURRENCE OF D STABILITY = 0.453718

RELATIVE FREQUENCY OF CALMS DISTRIBUTED ABOVE WITH D STABILITY = 0.039562

Table A-5 (Continued).

ANNUAL FREQUENCY DISTRIBUTIONS - STABILITY CLASS C   STATION =24135 BUTTE, MONTANA 56-60 6 OBS

	SPEED(KTS)						
DIRECTION	0 - 3	4 - 6	7 - 10	11 - 16	17 - 21	GREATER THAN 21	TOTAL
N	0.002929	0.003239	0.002481	0.000069	0.000000	0.000000	0.008719
NNE	0.002586	0.002068	0.001447	0.000138	0.000000	0.000000	0.006239
NE	0.001357	0.001241	0.000827	0.000069	0.000000	0.000000	0.003493
ENE	0.000895	0.000620	0.000758	0.000000	0.000000	0.000000	0.002273
E	0.000492	0.000482	0.000345	0.000069	0.000000	0.000000	0.001388
ESE	0.000973	0.000758	0.001654	0.000276	0.000000	0.000000	0.003661
SE	0.002980	0.001999	0.002068	0.000689	0.000138	0.000069	0.007942
SSE	0.002695	0.001310	0.001999	0.000482	0.000000	0.000000	0.006486
S	0.002695	0.001310	0.000414	0.000276	0.000069	0.000000	0.004762
SSW	0.001652	0.000620	0.001792	0.000276	0.000069	0.000000	0.004409
SW	0.001377	0.000896	0.001723	0.000689	0.000000	0.000000	0.004685
WSW	0.001003	0.000620	0.002068	0.000620	0.000276	0.000000	0.004587
W	0.000659	0.000414	0.001792	0.000207	0.000069	0.000000	0.003150
WNW	0.001957	0.001723	0.002757	0.001034	0.000138	0.000069	0.007677
NW	0.002192	0.002137	0.003929	0.000689	0.000069	0.000000	0.009016
NNW	0.002841	0.002895	0.004204	0.000482	0.000069	0.000000	0.010492
TOTAL	0.029292	0.022331	0.030257	0.006065	0.000896	0.000138	

RELATIVE FREQUENCY OF OCCURRENCE OF C STABILITY = 0.088979

RELATIVE FREQUENCY OF CALMS DISTRIBUTED ABOVE WITH C STABILITY = 0.018747

Table A-5 (Continued).

ANNUAL FREQUENCY DISTRIBUTIONS - STABILITY CLASS B   STATION =24135 BUTTE, MONTANA 56-60 8 OBS

	SPEED(KTS)						
DIRECTION	0 - 3	4 - 6	7 - 10	11 - 16	17 - 21	GREATER THAN 21	TOTAL
N	0.008538	0.002550	0.000620	0.000000	0.000000	0.000000	0.011709
NNE	0.005753	0.001447	0.000492	0.000000	0.000000	0.000000	0.007683
NE	0.005628	0.001861	0.000414	0.000000	0.000000	0.000000	0.007902
ENE	0.002923	0.000965	0.000414	0.000000	0.000000	0.000000	0.004302
E	0.002635	0.000965	0.000069	0.000000	0.000000	0.000000	0.003669
ESE	0.002986	0.000758	0.000207	0.000000	0.000000	0.000000	0.003951
SE	0.005303	0.001034	0.000620	0.000000	0.000000	0.000000	0.006957
SSE	0.004426	0.000758	0.000276	0.000000	0.000000	0.000000	0.005460
S	0.002536	0.000345	0.000207	0.000000	0.000000	0.000000	0.003087
SSW	0.002260	0.000620	0.000345	0.000000	0.000000	0.000000	0.003225
SW	0.001315	0.000414	0.000276	0.000000	0.000000	0.000000	0.002004
WSW	0.001684	0.000620	0.000138	0.000000	0.000000	0.000000	0.002442
W	0.001903	0.000689	0.000482	0.000000	0.000000	0.000000	0.003075
WNW	0.003124	0.000620	0.000827	0.000000	0.000000	0.000000	0.004571
NW	0.005666	0.001103	0.000896	0.000000	0.000000	0.000000	0.007664
NNW	0.005696	0.001792	0.000758	0.000000	0.000000	0.000000	0.008247
TOTAL	0.062375	0.016541	0.007030	0.000000	0.000000	0.000000	

RELATIVE FREQUENCY OF OCCURRENCE OF B STABILITY = 0.085947

RELATIVE FREQUENCY OF CALMS DISTRIBUTED ABOVE WITH B STABILITY = 0.041147

Table A-5 (Continued).

ANNUAL FREQUENCY DISTRIBUTIONS - STABILITY CLASS A STATION =24135 BUTTE, MONTANA 56-60 8 OBS

SPEED(KTS)

DIRECTION	0 - 3	4 - 6	7 - 10	11 - 16	17 - 21	GREATER THAN 21	TOTAL
N	0.001126	0.000207	0.000000	0.000000	0.000000	0.000000	0.001333
NNE	0.000264	0.000069	0.000000	0.000000	0.000000	0.000000	0.000333
NE	0.000999	0.000000	0.000000	0.000000	0.000000	0.000000	0.000999
ENE	0.000264	0.000069	0.000000	0.000000	0.000000	0.000000	0.000333
E	0.000264	0.000069	0.000000	0.000000	0.000000	0.000000	0.000333
ESE	0.000597	0.000069	0.000000	0.000000	0.000000	0.000000	0.000666
SE	0.000264	0.000069	0.000000	0.000000	0.000000	0.000000	0.000333
SSE	0.000333	0.000000	0.000000	0.000000	0.000000	0.000000	0.000333
S	0.000333	0.000000	0.000000	0.000000	0.000000	0.000000	0.000333
SSW	0.000930	0.000069	0.000000	0.000000	0.000000	0.000000	0.000999
SW	0.000862	0.000138	0.000000	0.000000	0.000000	0.000000	0.000999
WSW	0.000528	0.000138	0.000000	0.000000	0.000000	0.000000	0.000666
W	0.000264	0.000069	0.000000	0.000000	0.000000	0.000000	0.000333
WNW	0.000597	0.000069	0.000000	0.000000	0.000000	0.000000	0.000666
NW	0.000528	0.000138	0.000000	0.000000	0.000000	0.000000	0.000666
NNW	0.000528	0.000138	0.000000	0.000000	0.000000	0.000000	0.000666
TOTAL	0.008684	0.001310	0.000000	0.000000	0.000000	0.000000	

RELATIVE FREQUENCY OF OCCURRENCE OF A STABILITY = 0.009994

RELATIVE FREQUENCY OF CALMS DISTRIBUTED ABOVE WITH A STABILITY = 0.007926

Table A-6. Wind Distribution - Nashville, TN(1)

STATION = 13897 NASHVILLE,TN   8OBS 1974/78

ANNUAL FREQUENCY DISTRIBUTIONS - ALL STABILITY CLASSES

	SPEED(KTS)						
DIRECTION	0 - 3	4 - 6	7 - 10	11 - 16	17 - 21	GREATER THAN 21	TOTAL
N	.009330	.027603	.031233	.011233	.000411	.000000	.079809
NNE	.010881	.024658	.017945	.005000	.000068	.000000	.058552
NE	.013529	.027740	.013493	.002466	.000000	.000068	.057296
ENE	.009955	.016370	.006575	.000479	.000000	.000000	.033380
E	.010869	.018630	.006233	.000479	.000000	.000000	.036212
ESE	.009815	.015890	.006438	.000822	.000000	.000000	.032966
SE	.009467	.018562	.009726	.001918	.000137	.000000	.039809
SSE	.008981	.019589	.016918	.005000	.000753	.000068	.051310
S	.025357	.075685	.078082	.037671	.006575	.000616	.223987
SSW	.008627	.022808	.023767	.017329	.002740	.000342	.075613
SW	.005863	.013493	.019658	.014247	.001849	.000137	.055247
WSW	.005342	.014247	.014110	.009178	.001096	.000137	.044109
W	.007114	.015959	.020068	.014041	.001781	.000274	.059238
WNW	.003428	.007877	.015959	.010616	.001233	.000205	.039318
NW	.004318	.012329	.022808	.017808	.001233	.000137	.058633
NNW	.005137	.014452	.019795	.013973	.001164	.000000	.054520
TOTAL	.148014	.345890	.322808	.162260	.019041	.001986	

TOTAL RELATIVE FREQUENCY OF OBSERVATIONS = 1.000000

TOTAL RELATIVE FREQUENCY OF CALMS DISTRIBUTED ABOVE = .056986

(1) Data from Ref. [A-10].

Table A-6 (Continued).

ANNUAL FREQUENCY DISTRIBUTIONS - STABILITY CLASS F

STATION = 13897 NASHVILLE,TN 8085 1974/78

	SPEED(KTS)						
DIRECTION	0 - 3	4 - 6	7 - 10	11 - 16	17 - 21	GREATER THAN 21	TOTAL
N	.005256	.009110	.000000	.000000	.000000	.000000	.014366
NNE	.006715	.008904	.000000	.000000	.000000	.000000	.015619
NE	.008641	.010068	.000000	.000000	.000000	.000000	.018709
ENE	.004739	.002945	.000000	.000000	.000000	.000000	.007684
E	.006140	.004384	.000000	.000000	.000000	.000000	.010524
ESE	.006123	.005068	.000000	.000000	.000000	.000000	.011192
SE	.005173	.005685	.000000	.000000	.000000	.000000	.010858
SSE	.005739	.007123	.000000	.000000	.000000	.000000	.012862
S	.018945	.036096	.000000	.000000	.000000	.000000	.055041
SSW	.006085	.008699	.000000	.000000	.000000	.000000	.014783
SW	.003058	.004041	.000000	.000000	.000000	.000000	.007099
WSW	.003194	.004658	.000000	.000000	.000000	.000000	.007851
W	.003633	.005137	.000000	.000000	.000000	.000000	.008770
WNW	.001181	.001575	.000000	.000000	.000000	.000000	.002756
NW	.002161	.004521	.000000	.000000	.000000	.000000	.006682
NNW	.002875	.004726	.000000	.000000	.000000	.000000	.007601
TOTAL	.089658	.122740	.000000	.000000	.000000	.000000	

RELATIVE FREQUENCY OF OCCURRENCE OF F STABILITY = .212397

RELATIVE FREQUENCY OF CALMS DISTRIBUTED ABOVE WITH F STABILITY = .038219

Table A-6 (Continued).

ANNUAL FREQUENCY DISTRIBUTIONS - STABILITY CLASS E

STATION = 13897 NASHVILLE,TN   8OBS 1974778

	SPEED(KTS)						
DIRECTION	0 - 3	4 - 6	7 - 10	11 - 16	17 - 21	GREATER THAN 21	TOTAL
N	.000000	.004589	.006301	.000000	.000000	.000000	.010890
NNE	.000000	.004589	.003014	.000000	.000000	.000000	.007603
NE	.000000	.005822	.002055	.000000	.000000	.000000	.007877
ENE	.000000	.003699	.000411	.000000	.000000	.000000	.004110
E	.000000	.003425	.000274	.000000	.000000	.000000	.003699
ESE	.000000	.003973	.000616	.000000	.000000	.000000	.004589
SE	.000000	.004932	.001233	.000000	.000000	.000000	.006164
SSE	.000000	.004384	.003493	.000000	.000000	.000000	.007877
S	.000000	.018836	.024726	.000000	.000000	.000000	.043562
SSW	.000000	.004384	.004521	.000000	.000000	.000000	.008904
SW	.000000	.002603	.002740	.000000	.000000	.000000	.005342
WSW	.000000	.002260	.002055	.000000	.000000	.000000	.004315
W	.000000	.002055	.003904	.000000	.000000	.000000	.005959
WNW	.000000	.001096	.002123	.000000	.000000	.000000	.003219
NW	.000000	.001507	.004521	.000000	.000000	.000000	.006027
NNW	.000000	.003082	.004247	.000000	.000000	.000000	.007329
TOTAL	.000000	.071233	.066233	.000000	.000000	.000000	

RELATIVE FREQUENCY OF OCCURRENCE OF E STABILITY = .137466

RELATIVE FREQUENCY OF CALMS DISTRIBUTED ABOVE WITH E STABILITY = .000000

Table A-6 (Continued).

ANNUAL FREQUENCY DISTRIBUTIONS - STABILITY CLASS D

STATION = 13897 NASHVILLE,TN 80BS 1974/78

	SPEED(KTS)						
DIRECTION	0 - 3	4 - 6	7 - 10	11 - 16	17 - 21	GREATER THAN 21	TOTAL
N	.001481	.007055	.017671	.010548	.000411	.000000	.037166
NNE	.001691	.006918	.008836	.004589	.000068	.000000	.022102
NE	.002029	.006507	.006096	.001712	.000000	.000068	.016413
ENE	.001699	.004795	.002466	.000411	.000000	.000000	.009370
E	.001259	.005890	.003493	.000411	.000000	.000000	.011054
ESE	.001061	.003973	.003493	.000685	.000000	.000000	.009212
SE	.001106	.004658	.006575	.001781	.000137	.000000	.014257
SSE	.000597	.003562	.010548	.004658	.000753	.000068	.020186
S	.002254	.012192	.039932	.036301	.006507	.000616	.097802
SSW	.000746	.004726	.013219	.016507	.002740	.000342	.038280
SW	.000725	.003288	.009589	.013151	.001849	.000137	.028739
WSW	.000619	.003904	.006781	.007603	.001027	.000137	.020071
W	.001183	.004726	.009863	.012945	.001781	.000274	.030773
WNW	.000421	.001986	.009178	.009795	.001233	.000205	.022819
NW	.000692	.003904	.013630	.017260	.001233	.000137	.036857
NNW	.000860	.004247	.012808	.013767	.001096	.000000	.032778
TOTAL	.018425	.082329	.174178	.152123	.018836	.001986	

RELATIVE FREQUENCY OF OCCURRENCE OF D STABILITY = .447877

RELATIVE FREQUENCY OF CALMS DISTRIBUTED ABOVE WITH D STABILITY = .006164

Table A-6 (Continued).

STATION = 13897 NASHVILLE,TN 8OBS 1974/78

ANNUAL FREQUENCY DISTRIBUTIONS - STABILITY CLASS C

	SPEED(KTS)						
DIRECTION	0 - 3	4 - 6	7 - 10	11 - 16	17 - 21	GREATER THAN 21	TOTAL
N	.000981	.003356	.005274	.000685	.000000	.000000	.010296
NNE	.000698	.001781	.004247	.000411	.000000	.000000	.007136
NE	.000811	.002055	.003151	.000753	.000000	.000000	.006770
ENE	.000835	.001644	.002534	.000068	.000000	.000000	.005081
E	.000769	.002329	.001644	.000068	.000000	.000000	.004810
ESE	.000602	.001644	.001644	.000137	.000000	.000000	.004027
SE	.000662	.001507	.001712	.000137	.000000	.000000	.004018
SSE	.000647	.001986	.002466	.000342	.000000	.000000	.005442
S	.002203	.005000	.009658	.001370	.000068	.000000	.018299
SSW	.000701	.002397	.004795	.000822	.000000	.000000	.008715
SW	.000480	.001301	.005822	.001096	.000000	.000000	.008699
WSW	.000429	.001507	.003699	.001575	.000068	.000000	.007279
W	.000602	.001644	.004795	.001096	.000000	.000000	.008137
WNW	.000221	.001096	.003356	.000822	.000000	.000000	.005495
NW	.000239	.001233	.003493	.000548	.000000	.000000	.005513
NNW	.000489	.001370	.001781	.000205	.000068	.000000	.003914
TOTAL	.011370	.031849	.060068	.010137	.000205	.000000	

RELATIVE FREQUENCY OF OCCURRENCE OF C STABILITY = .113630

RELATIVE FREQUENCY OF CALMS DISTRIBUTED ABOVE WITH C STABILITY = .005000

Table A-6 (Continued).

ANNUAL FREQUENCY DISTRIBUTIONS - STABILITY CLASS B

STATION - 13897 NASHVILLE,TN   8085 1974/78

				SPEED(KTS)			
DIRECTION	0 - 3	4 - 6	7 - 10	11 - 16	17 - 21	GREATER THAN 21	TOTAL
N	.001206	.002877	.001986	.000000	.000000	.000000	.006069
NNE	.001440	.002123	.001849	.000000	.000000	.000000	.005413
NE	.001800	.002877	.002192	.000000	.000000	.000000	.006869
ENE	.001863	.002740	.001164	.000000	.000000	.000000	.005767
E	.002126	.002329	.000822	.000000	.000000	.000000	.005276
ESE	.001799	.001096	.000685	.000000	.000000	.000000	.003580
SE	.001908	.001507	.000205	.000000	.000000	.000000	.003620
SSE	.001612	.002397	.000411	.000000	.000000	.000000	.004420
S	.002326	.002945	.003767	.000000	.000000	.000000	.009038
SSW	.001046	.001849	.001233	.000000	.000000	.000000	.004128
SW	.001137	.002055	.001507	.000000	.000000	.000000	.004699
WSW	.000886	.001712	.001575	.000000	.000000	.000000	.004174
W	.001514	.002123	.001507	.000000	.000000	.000000	.005145
WNW	.001126	.001918	.001301	.000000	.000000	.000000	.004345
NW	.001046	.000959	.001164	.000000	.000000	.000000	.003169
NNW	.000589	.000822	.000959	.000000	.000000	.000000	.002369
TOTAL	.023425	.032329	.022329	.000000	.000000	.000000	

RELATIVE FREQUENCY OF OCCURRENCE OF B STABILITY = .078082

RELATIVE FREQUENCY OF CALMS DISTRIBUTED ABOVE WITH B STABILITY = .004315

Table A-6 (Continued).

ANNUAL FREQUENCY DISTRIBUTIONS - STABILITY CLASS A

STATION - 13897 NASHVILLE,TN   #OBS 1974/78

	SPEED(KTS)						
DIRECTION	0 - 3	4 - 6	7 - 10	11 - 16	17 - 21	GREATER THAN 21	TOTAL
N	.000379	.000616	.000000	.000000	.000000	.000000	.000995
NNE	.000354	.000342	.000000	.000000	.000000	.000000	.000697
NE	.000286	.000411	.000000	.000000	.000000	.000000	.000697
ENE	.000547	.000548	.000000	.000000	.000000	.000000	.001095
E	.000423	.000274	.000000	.000000	.000000	.000000	.000697
ESE	.000162	.000137	.000000	.000000	.000000	.000000	.000299
SE	.000423	.000274	.000000	.000000	.000000	.000000	.000697
SSE	.000460	.000137	.000000	.000000	.000000	.000000	.000597
S	.000279	.000616	.000000	.000000	.000000	.000000	.000896
SSW	.000341	.000753	.000000	.000000	.000000	.000000	.001095
SW	.000392	.000205	.000000	.000000	.000000	.000000	.000597
WSW	.000193	.000205	.000000	.000000	.000000	.000000	.000398
W	.000124	.000274	.000000	.000000	.000000	.000000	.000398
WNW	.000392	.000205	.000000	.000000	.000000	.000000	.000597
NW	.000193	.000205	.000000	.000000	.000000	.000000	.000398
NNW	.000193	.000205	.000000	.000000	.000000	.000000	.000398
TOTAL	.005137	.005411	.000000	.000000	.000000	.000000	

RELATIVE FREQUENCY OF OCCURRENCE OF A STABILITY = .010548

RELATIVE FREQUENCY OF CALMS DISTRIBUTED ABOVE WITH A STABILITY = .003288

Table A-7. Wind Distribution - Pocatello, ID[1]

ANNUAL FREQUENCY DISTRIBUTIONS - ALL STABILITY CLASSES   STATION =24156 POCATELLO, IDAHO 58-62 24 OBS

	SPEED(KTS)						
DIRECTION	0 - 3	4 - 6	7 - 10	11 - 16	17 - 21	GREATER THAN 21	TOTAL
N	0.009161	0.022147	0.013265	0.003082	0.000342	0.000046	0.048044
NNE	0.008760	0.020823	0.017261	0.005503	0.001301	0.000502	0.054150
NE	0.012506	0.020220	0.021690	0.006690	0.001301	0.000114	0.070522
ENE	0.005379	0.014202	0.010160	0.002192	0.000297	0.000000	0.032230
E	0.007158	0.015845	0.008060	0.001142	0.000091	0.000023	0.032319
ESE	0.004013	0.004918	0.002169	0.000548	0.000068	0.000023	0.013739
SE	0.005169	0.008813	0.003539	0.001370	0.000388	0.000046	0.019325
SSE	0.003654	0.006667	0.006576	0.006850	0.005548	0.002603	0.031897
S	0.006966	0.017444	0.030275	0.029202	0.018403	0.008676	0.110966
SSW	0.007522	0.023494	0.053381	0.058952	0.007535	0.001187	0.132071
SW	0.007521	0.025846	0.052514	0.061761	0.021919	0.007101	0.178661
WSW	0.005345	0.013174	0.026166	0.044888	0.027284	0.018015	0.134872
W	0.005333	0.011462	0.015252	0.018882	0.009955	0.005777	0.066660
WNW	0.002927	0.006735	0.006918	0.004384	0.001073	0.000457	0.022489
NW	0.005590	0.012717	0.008425	0.002123	0.000388	0.000160	0.029403
NNW	0.004020	0.009909	0.007306	0.001279	0.000137	0.000000	0.022651
TOTAL	0.103010	0.244417	0.282958	0.220846	0.096032	0.044728	

TOTAL RELATIVE FREQUENCY OF OBSERVATIONS = 1.000000

TOTAL RELATIVE FREQUENCY OF CALMS DISTRIBUTED ABOVE = 0.048450

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(1) Data from Ref. [A-11].

Table A-7 (Continued).

ANNUAL FREQUENCY DISTRIBUTIONS - STABILITY CLASS F   STATION =24156 POCATELLO, IDAHO 58-62 24 OBS

	SPEED(KTS)						
DIRECTION	0 - 3	4 - 6	7 - 10	11 - 16	17 - 21	GREATER THAN 21	TOTAL
N	0.004314	0.006393	0.000000	0.000000	0.000000	0.000000	0.010707
NNE	0.004405	0.005046	0.000000	0.000000	0.000000	0.000000	0.009450
NE	0.005901	0.006918	0.000000	0.000000	0.000000	0.000000	0.012820
ENE	0.002937	0.004201	0.000000	0.000000	0.000000	0.000000	0.007138
E	0.004359	0.006119	0.000000	0.000000	0.000000	0.000000	0.010478
ESE	0.002605	0.002420	0.000000	0.000000	0.000000	0.000000	0.005025
SE	0.003610	0.004041	0.000000	0.000000	0.000000	0.000000	0.007652
SSE	0.002617	0.003493	0.000000	0.000000	0.000000	0.000000	0.006110
S	0.005577	0.008585	0.000000	0.000000	0.000000	0.000000	0.014161
SSW	0.005532	0.011256	0.000000	0.000000	0.000000	0.000000	0.016788
SW	0.006223	0.010366	0.000000	0.000000	0.000000	0.000000	0.016588
WSW	0.002965	0.004315	0.000000	0.000000	0.000000	0.000000	0.007281
W	0.002674	0.003151	0.000000	0.000000	0.000000	0.000000	0.005824
WNW	0.001245	0.001438	0.000000	0.000000	0.000000	0.000000	0.002684
NW	0.002965	0.003859	0.000000	0.000000	0.000000	0.000000	0.006824
NNW	0.002006	0.003219	0.000000	0.000000	0.000000	0.000000	0.005225
TOTAL	0.059934	0.084821	0.000000	0.000000	0.000000	0.000000	

RELATIVE FREQUENCY OF OCCURRENCE OF F STABILITY = 0.144755

RELATIVE FREQUENCY OF CALMS DISTRIBUTED ABOVE WITH F STABILITY = 0.028997

Table A-7 (Continued).

ANNUAL FREQUENCY DISTRIBUTIONS - STABILITY CLASS E   STATION =24156 POCATELLO, IDAHO 58-62 24 OBS

	SPEED(KTS)						
DIRECTION	0 - 3	4 - 6	7 - 10	11 - 16	17 - 21	GREATER THAN 21	TOTAL
N	0.000000	0.003996	0.003539	0.000000	0.000000	0.000000	0.007535
NNE	0.000000	0.003448	0.002945	0.000000	0.000000	0.000000	0.006393
NE	0.000000	0.005799	0.005000	0.000000	0.000000	0.000000	0.010800
ENE	0.000000	0.002968	0.002831	0.000000	0.000000	0.000000	0.005799
E	0.000000	0.003470	0.002945	0.000000	0.000000	0.000000	0.006416
ESE	0.000000	0.001644	0.000388	0.000000	0.000000	0.000000	0.002032
SE	0.000000	0.001941	0.001187	0.000000	0.000000	0.000000	0.003128
SSE	0.000000	0.001324	0.002260	0.000000	0.000000	0.000000	0.003585
S	0.000000	0.004041	0.014498	0.000000	0.000000	0.000000	0.018540
SSW	0.000000	0.005662	0.024202	0.000000	0.000000	0.000000	0.029864
SW	0.000000	0.005023	0.015823	0.000000	0.000000	0.000000	0.020846
WSW	0.000000	0.002329	0.003653	0.000000	0.000000	0.000000	0.005982
W	0.000000	0.001530	0.001484	0.000000	0.000000	0.000000	0.003014
WNW	0.000000	0.001027	0.000594	0.000000	0.000000	0.000000	0.001621
NW	0.000000	0.002215	0.001324	0.000000	0.000000	0.000000	0.003539
NNW	0.000000	0.001781	0.001964	0.000000	0.000000	0.000000	0.003744
TOTAL	0.000000	0.048199	0.084638	0.000000	0.000000	0.000000	

RELATIVE FREQUENCY OF OCCURRENCE OF E STABILITY = 0.132837

RELATIVE FREQUENCY OF CALMS DISTRIBUTED ABOVE WITH E STABILITY = 0.000000

Table A-7 (Continued).

ANNUAL FREQUENCY DISTRIBUTIONS - STABILITY CLASS D

STATION #24156 POCATELLO, IDAHO 58-62 24 OBS

	SPEED(KTS)						
DIRECTION	0 - 3	4 - 6	7 - 10	11 - 16	17 - 21	GREATER THAN 21	TOTAL
N	0.001432	0.005799	0.005411	0.002283	0.000342	0.000046	0.015314
NNE	0.001162	0.005617	0.007923	0.005069	0.001279	0.000502	0.021551
NE	0.002151	0.007626	0.010457	0.006370	0.001279	0.000114	0.027997
ENE	0.000737	0.003219	0.004635	0.001986	0.000297	0.000000	0.010874
E	0.000965	0.003722	0.003607	0.001073	0.000091	0.000023	0.009482
ESE	0.000720	0.001598	0.001256	0.000548	0.000068	0.000023	0.004213
SE	0.000637	0.001530	0.001872	0.001301	0.000365	0.000046	0.005752
SSE	0.000436	0.001050	0.003790	0.006713	0.005503	0.002603	0.020095
S	0.000631	0.003174	0.014156	0.028860	0.018334	0.008562	0.073717
SSW	0.000856	0.004612	0.026188	0.038723	0.007443	0.001164	0.078987
SW	0.001173	0.006210	0.030663	0.060688	0.021668	0.007078	0.127480
WSW	0.000688	0.002991	0.013288	0.041212	0.025755	0.017284	0.101218
W	0.000613	0.002512	0.006370	0.015594	0.008973	0.005503	0.039565
WNW	0.000438	0.001553	0.002192	0.003493	0.000890	0.000457	0.009023
NW	0.000519	0.002329	0.002877	0.001575	0.000388	0.000160	0.007848
NNW	0.000678	0.002169	0.002489	0.000913	0.000137	0.000000	0.006386
TOTAL	0.013836	0.055710	0.137175	0.216402	0.092812	0.043564	

RELATIVE FREQUENCY OF OCCURRENCE OF D STABILITY = 0.559500

RELATIVE FREQUENCY OF CALMS DISTRIBUTED ABOVE WITH D STABILITY = 0.006530

Table A-7 (Continued).

ANNUAL FREQUENCY DISTRIBUTIONS - STABILITY CLASS C   STATION =24156 POCATELLO, IDAHO 58-62 24 OBS

DIRECTION	SPEED(KTS) 0 - 3	4 - 6	7 - 10	11 - 16	17 - 21	GREATER THAN 21	TOTAL
N	0.000975	0.003356	0.002991	0.000799	0.000000	0.000000	0.008121
NNE	0.001116	0.004178	0.004795	0.000434	0.000023	0.000000	0.010545
NE	0.001299	0.004932	0.004886	0.000320	0.000023	0.000000	0.011460
ENE	0.000665	0.002603	0.001941	0.000205	0.000000	0.000000	0.005414
E	0.000613	0.001667	0.001164	0.000068	0.000000	0.000000	0.003513
ESE	0.000176	0.000685	0.000479	0.000000	0.000000	0.000000	0.001341
SE	0.000379	0.000685	0.000388	0.000068	0.000023	0.000000	0.001543
SSE	0.000225	0.000434	0.000411	0.000137	0.000046	0.000000	0.001252
S	0.000378	0.001142	0.001370	0.000342	0.000068	0.000114	0.003415
SSW	0.000538	0.001210	0.002512	0.000228	0.000091	0.000023	0.004602
SW	0.000659	0.002786	0.005320	0.001073	0.000251	0.000023	0.010112
WSW	0.000582	0.002078	0.007557	0.003676	0.001530	0.000731	0.016153
W	0.000589	0.002146	0.005982	0.003288	0.000982	0.000274	0.013261
WNW	0.000313	0.001005	0.002808	0.000890	0.000183	0.000000	0.005199
NW	0.000749	0.002215	0.002854	0.000548	0.000000	0.000000	0.006365
NNW	0.000426	0.001119	0.002009	0.000365	0.000000	0.000000	0.003920
TOTAL	0.009681	0.032239	0.047468	0.012443	0.003219	0.001164	

RELATIVE FREQUENCY OF OCCURRENCE OF C STABILITY = 0.106215

RELATIVE FREQUENCY OF CALMS DISTRIBUTED ABOVE WITH C STABILITY = 0.004133

Table A-7 (Continued).

ANNUAL FREQUENCY DISTRIBUTIONS - STABILITY CLASS B STATION =24156 POCATELLO, IDAHO 58-62 24 OBS

	SPEED(KTS)						
DIRECTION	0 - 3	4 - 6	7 - 10	11 - 16	17 - 21	GREATER THAN 21	TOTAL
N	0.001995	0.002169	0.001324	0.000000	0.000000	0.000000	0.005489
NNE	0.001666	0.002443	0.001598	0.000000	0.000000	0.000000	0.005708
NE	0.002407	0.002557	0.001347	0.000000	0.000000	0.000000	0.006311
ENE	0.000710	0.001027	0.000753	0.000000	0.000000	0.000000	0.002491
E	0.001025	0.000685	0.000342	0.000000	0.000000	0.000000	0.002052
ESE	0.000458	0.000479	0.000046	0.000000	0.000000	0.000000	0.000983
SE	0.000573	0.000502	0.000091	0.000000	0.000000	0.000000	0.001167
SSE	0.000461	0.000228	0.000114	0.000000	0.000000	0.000000	0.000804
S	0.000416	0.000411	0.000251	0.000000	0.000000	0.000000	0.001079
SSW	0.000529	0.000685	0.000479	0.000000	0.000000	0.000000	0.001693
SW	0.001290	0.001164	0.000708	0.000000	0.000000	0.000000	0.003162
WSW	0.000974	0.001370	0.001667	0.000000	0.000000	0.000000	0.004011
W	0.001331	0.001758	0.001416	0.000000	0.000000	0.000000	0.004504
WNW	0.000815	0.001530	0.001324	0.000000	0.000000	0.000000	0.003669
NW	0.001198	0.001781	0.001370	0.000000	0.000000	0.000000	0.004349
NNW	0.000818	0.001416	0.000845	0.000000	0.000000	0.000000	0.003079
TOTAL	0.016667	0.020206	0.013676	0.000000	0.000000	0.000000	

RELATIVE FREQUENCY OF OCCURRENCE OF B STABILITY = 0.050550

RELATIVE FREQUENCY OF CALMS DISTRIBUTED ABOVE WITH B STABILITY = 0.006347

Table A-7 (Continued).

ANNUAL FREQUENCY DISTRIBUTIONS - STABILITY CLASS A

STATION #24156 POCATELLO, IDAHO 58-62 24 OBS

	SPEED(KTS)						
DIRECTION	0 - 3	4 - 6	7 - 10	11 - 16	17 - 21	GREATER THAN 21	TOTAL
N	0.000362	0.000434	0.000000	0.000000	0.000000	0.000000	0.000796
NNE	0.000136	0.000091	0.000000	0.000000	0.000000	0.000000	0.000227
NE	0.000294	0.000388	0.000000	0.000000	0.000000	0.000000	0.000682
ENE	0.000159	0.000183	0.000000	0.000000	0.000000	0.000000	0.000341
E	0.000196	0.000183	0.000000	0.000000	0.000000	0.000000	0.000379
ESE	0.000060	0.000091	0.000000	0.000000	0.000000	0.000000	0.000152
SE	0.000151	0.000114	0.000000	0.000000	0.000000	0.000000	0.000265
SSE	0.000128	0.000137	0.000000	0.000000	0.000000	0.000000	0.000265
S	0.000136	0.000091	0.000000	0.000000	0.000000	0.000000	0.000227
SSW	0.000045	0.000068	0.000000	0.000000	0.000000	0.000000	0.000114
SW	0.000234	0.000297	0.000000	0.000000	0.000000	0.000000	0.000531
WSW	0.000098	0.000091	0.000000	0.000000	0.000000	0.000000	0.000190
W	0.000317	0.000365	0.000000	0.000000	0.000000	0.000000	0.000682
WNW	0.000157	0.000183	0.000000	0.000000	0.000000	0.000000	0.000341
NW	0.000287	0.000320	0.000000	0.000000	0.000000	0.000000	0.000607
NNW	0.000136	0.000205	0.000000	0.000000	0.000000	0.000000	0.000341
TOTAL	0.002900	0.003242	0.000000	0.000000	0.000000	0.000000	

RELATIVE FREQUENCY OF OCCURRENCE OF A STABILITY = 0.006142

RELATIVE FREQUENCY OF CALMS DISTRIBUTED ABOVE WITH A STABILITY = 0.002443

Table A-8. Wind Distribution - Tampa, FL(1)

ANNUAL FREQUENCY DISTRIBUTIONS - ALL STABILITY CLASSES STATION =12842 TAMPA,FL 8OBS 1969-73

	SPEED(KTS)						
DIRECTION	0 - 3	4 - 6	7 - 10	11 - 16	17 - 21	GREATER THAN 21	TOTAL
N	0.005818	0.019592	0.019660	0.008974	0.000274	0.000000	0.054318
NNE	0.004616	0.016167	0.016441	0.007398	0.000137	0.000000	0.044759
NE	0.007206	0.026168	0.024661	0.011508	0.000206	0.000000	0.069749
ENE	0.012145	0.041102	0.036101	0.012741	0.000274	0.000000	0.102363
E	0.018037	0.065625	0.055282	0.020551	0.000617	0.000000	0.160111
ESE	0.010583	0.030073	0.028840	0.011371	0.000274	0.000000	0.081140
SE	0.006677	0.019112	0.023496	0.008768	0.000137	0.000000	0.058191
SSE	0.005299	0.018290	0.021167	0.007330	0.000343	0.000000	0.052429
S	0.004751	0.016715	0.020551	0.010344	0.000685	0.000137	0.053182
SSW	0.002587	0.008563	0.014523	0.007398	0.000617	0.000000	0.033687
SW	0.002419	0.011234	0.012604	0.003631	0.000137	0.000000	0.030025
WSW	0.002702	0.010344	0.018427	0.005480	0.000137	0.000000	0.037091
W	0.004235	0.016852	0.042335	0.024113	0.000411	0.000000	0.087945
WNW	0.003637	0.011988	0.013701	0.010755	0.001302	0.000343	0.041724
NW	0.004440	0.016646	0.015961	0.010823	0.001781	0.000480	0.050131
NNW	0.004246	0.013426	0.013358	0.010275	0.001644	0.000206	0.043156
TOTAL	0.099397	0.341896	0.377106	0.171462	0.008974	0.001165	

TOTAL RELATIVE FREQUENCY OF OBSERVATIONS = 1.000001

TOTAL RELATIVE FREQUENCY OF CALMS DISTRIBUTED ABOVE = 0.042746

(1) Data from Ref. [A-12].

Table A-8 (Continued).

ANNUAL FREQUENCY DISTRIBUTIONS - STABILITY CLASS G   STATION =12842 TAMPA,FL   8OBS   1969-73

	SPEED(KTS)						
DIRECTION	0 - 3	4 - 6	7 - 10	11 - 16	17 - 21	GREATER THAN 21	TOTAL
N	0.003188	0.000000	0.000000	0.000000	0.000000	0.000000	0.003188
NNE	0.002295	0.000000	0.000000	0.000000	0.000000	0.000000	0.002295
NE	0.004336	0.000000	0.000000	0.000000	0.000000	0.000000	0.004336
ENE	0.006504	0.000000	0.000000	0.000000	0.000000	0.000000	0.006504
E	0.010585	0.000000	0.000000	0.000000	0.000000	0.000000	0.010585
ESE	0.006376	0.000000	0.000000	0.000000	0.000000	0.000000	0.006376
SE	0.004336	0.000000	0.000000	0.000000	0.000000	0.000000	0.004336
SSE	0.002423	0.000000	0.000000	0.000000	0.000000	0.000000	0.002423
S	0.002040	0.000000	0.000000	0.000000	0.000000	0.000000	0.002040
SSW	0.000893	0.000000	0.000000	0.000000	0.000000	0.000000	0.000893
SW	0.000765	0.000000	0.000000	0.000000	0.000000	0.000000	0.000765
WSW	0.000893	0.000000	0.000000	0.000000	0.000000	0.000000	0.000893
W	0.001530	0.000000	0.000000	0.000000	0.000000	0.000000	0.001530
WNW	0.001275	0.000000	0.000000	0.000000	0.000000	0.000000	0.001275
NW	0.002678	0.000000	0.000000	0.000000	0.000000	0.000000	0.002678
NNW	0.002423	0.000000	0.000000	0.000000	0.000000	0.000000	0.002423
TOTAL	0.052541	0.000000	0.000000	0.000000	0.000000	0.000000	

RELATIVE FREQUENCY OF OCCURRENCE OF G STABILITY = 0.052541

RELATIVE FREQUENCY OF CALMS DISTRIBUTED ABOVE WITH G STABILITY = 0.024318

Table A-8 (Continued).

ANNUAL FREQUENCY DISTRIBUTIONS - STABILITY CLASS F   STATION =12842 TAMPA,FL   8OBS   1969-73

	SPEED(KTS)						
DIRECTION	0 - 3	4 - 6	7 - 10	11 - 16	17 - 21	GREATER THAN 21	TOTAL
N	0.001728	0.009590	0.000000	0.000000	0.000000	0.000000	0.011319
NNE	0.001493	0.006645	0.000000	0.000000	0.000000	0.000000	0.008138
NE	0.002219	0.012947	0.000000	0.000000	0.000000	0.000000	0.015166
ENE	0.004304	0.019592	0.000000	0.000000	0.000000	0.000000	0.023895
E	0.005692	0.030484	0.000000	0.000000	0.000000	0.000000	0.036176
ESE	0.003093	0.011851	0.000000	0.000000	0.000000	0.000000	0.014944
SE	0.001619	0.006371	0.000000	0.000000	0.000000	0.000000	0.007990
SSE	0.001614	0.006302	0.000000	0.000000	0.000000	0.000000	0.007916
S	0.001085	0.004316	0.000000	0.000000	0.000000	0.000000	0.005400
SSW	0.000666	0.001850	0.000000	0.000000	0.000000	0.000000	0.002515
SW	0.000611	0.003014	0.000000	0.000000	0.000000	0.000000	0.003625
WSW	0.000931	0.002398	0.000000	0.000000	0.000000	0.000000	0.003329
W	0.001063	0.004042	0.000000	0.000000	0.000000	0.000000	0.005105
WNW	0.001123	0.004795	0.000000	0.000000	0.000000	0.000000	0.005918
NW	0.001304	0.008905	0.000000	0.000000	0.000000	0.000000	0.010209
NNW	0.001392	0.006302	0.000000	0.000000	0.000000	0.000000	0.007694
TOTAL	0.029936	0.139402	0.000000	0.000000	0.000000	0.000000	

RELATIVE FREQUENCY OF OCCURRENCE OF F STABILITY = 0.169338

RELATIVE FREQUENCY OF CALMS DISTRIBUTED ABOVE WITH F STABILITY = 0.012536

Table A-8 (Continued).

ANNUAL FREQUENCY DISTRIBUTIONS - STABILITY CLASS E   STATION =12842 TAMPA,FL 80BS   1969-73

	SPEED(KTS)						
DIRECTION	0 - 3	4 - 6	7 - 10	11 - 16	17 - 21	GREATER THAN 21	TOTAL
N	0.000000	0.005343	0.006439	0.000000	0.000000	0.000000	0.011782
NNE	0.000000	0.004316	0.004864	0.000000	0.000000	0.000000	0.009179
NE	0.000000	0.006713	0.007124	0.000000	0.000000	0.000000	0.013838
ENE	0.000000	0.013221	0.010412	0.000000	0.000000	0.000000	0.023633
E	0.000000	0.019249	0.013289	0.000000	0.000000	0.000000	0.032539
ESE	0.000000	0.010344	0.006576	0.000000	0.000000	0.000000	0.016920
SE	0.000000	0.005480	0.005069	0.000000	0.000000	0.000000	0.010549
SSE	0.000000	0.005549	0.002946	0.000000	0.000000	0.000000	0.008494
S	0.000000	0.005343	0.002672	0.000000	0.000000	0.000000	0.008015
SSW	0.000000	0.002466	0.001028	0.000000	0.000000	0.000000	0.003494
SW	0.000000	0.003494	0.001233	0.000000	0.000000	0.000000	0.004727
WSW	0.000000	0.001781	0.001850	0.000000	0.000000	0.000000	0.003631
W	0.000000	0.004042	0.004179	0.000000	0.000000	0.000000	0.008220
WNW	0.000000	0.004179	0.003562	0.000000	0.000000	0.000000	0.007741
NW	0.000000	0.005275	0.006028	0.000000	0.000000	0.000000	0.011303
NNW	0.000000	0.004247	0.004384	0.000000	0.000000	0.000000	0.008631
TOTAL	0.000000	0.101041	0.081655	0.000000	0.000000	0.000000	

RELATIVE FREQUENCY OF OCCURRENCE OF E STABILITY = 0.182696

RELATIVE FREQUENCY OF CALMS DISTRIBUTED ABOVE WITH E STABILITY = 0.000000

Table A-8 (Continued).

ANNUAL FREQUENCY DISTRIBUTIONS - STABILITY CLASS D   STATION =12842 TAMPA,FL   8OBS   1969-73

	SPEED(KTS)						
DIRECTION	0 - 3	4 - 6	7 - 10	11 - 16	17 - 21	GREATER THAN 21	TOTAL
N	0.000424	0.001918	0.008631	0.008563	0.000274	0.000000	0.019811
NNE	0.000236	0.002603	0.007330	0.006576	0.000137	0.000000	0.016882
NE	0.000340	0.003494	0.011645	0.010755	0.000206	0.000000	0.026439
ENE	0.000600	0.004795	0.016852	0.011782	0.000274	0.000000	0.034303
E	0.000746	0.009837	0.028223	0.018359	0.000617	0.000000	0.056781
ESE	0.000496	0.003905	0.014180	0.010207	0.000274	0.000000	0.029062
SE	0.000274	0.003631	0.011303	0.008494	0.000137	0.000000	0.023838
SSE	0.000307	0.002603	0.010001	0.006302	0.000343	0.000000	0.019557
S	0.000489	0.003699	0.011097	0.008974	0.000685	0.000069	0.025013
SSW	0.000268	0.001507	0.006028	0.005891	0.000617	0.000000	0.014311
SW	0.000275	0.001713	0.004179	0.002946	0.000137	0.000000	0.009249
WSW	0.000128	0.001576	0.005412	0.004521	0.000137	0.000000	0.011774
W	0.000459	0.002877	0.015002	0.017674	0.000206	0.000000	0.036218
WNW	0.000405	0.001370	0.006576	0.009522	0.001233	0.000274	0.019380
NW	0.000194	0.001439	0.006576	0.010070	0.001644	0.000480	0.020402
NNW	0.000250	0.001028	0.006028	0.009590	0.001507	0.000206	0.018609
TOTAL	0.005891	0.046993	0.169064	0.150226	0.008426	0.001028	

RELATIVE FREQUENCY OF OCCURRENCE OF D STABILITY = 0.381628

RELATIVE FREQUENCY OF CALMS DISTRIBUTED ABOVE WITH D STABILITY = 0.001850

Table A-8 (Continued).

ANNUAL FREQUENCY DISTRIBUTIONS - STABILITY CLASS C   STATION =12842 TAMPA,FL   8OBS   1969-73

	SPEED(KTS)						
DIRECTION	0 - 3	4 - 6	7 - 10	11 - 16	17 - 21	GREATER THAN 21	TOTAL
N	0.000193	0.000959	0.003562	0.000411	0.000000	0.000000	0.005125
NNE	0.000183	0.000754	0.003220	0.000822	0.000000	0.000000	0.004978
NE	0.000211	0.001302	0.005001	0.000754	0.000000	0.000000	0.007266
ENE	0.000267	0.002398	0.007467	0.000959	0.000000	0.000000	0.011090
E	0.000537	0.004864	0.011919	0.002192	0.000000	0.000000	0.019512
ESE	0.000177	0.002055	0.006782	0.001165	0.000000	0.000000	0.010178
SE	0.000437	0.001507	0.005891	0.000274	0.000000	0.000000	0.008109
SSE	0.000235	0.001781	0.006782	0.001028	0.000000	0.000000	0.009825
S	0.000211	0.001302	0.005549	0.001370	0.000000	0.000069	0.008499
SSW	0.000207	0.001233	0.005686	0.001507	0.000000	0.000000	0.008633
SW	0.000077	0.001507	0.004864	0.000685	0.000000	0.000000	0.007133
WSW	0.000263	0.002329	0.007672	0.000959	0.000000	0.000000	0.011223
W	0.000112	0.002192	0.017126	0.006439	0.000206	0.000000	0.026074
WNW	0.000251	0.000685	0.002877	0.001233	0.000069	0.000069	0.005183
NW	0.000018	0.000343	0.002809	0.000754	0.000137	0.000000	0.004059
NNW	0.000049	0.000959	0.002261	0.000685	0.000137	0.000000	0.004091
TOTAL	0.003425	0.026168	0.099466	0.021236	0.000548	0.000137	

RELATIVE FREQUENCY OF OCCURRENCE OF C STABILITY = 0.150980

RELATIVE FREQUENCY OF CALMS DISTRIBUTED ABOVE WITH C STABILITY = 0.001439

Table A-8 (Continued).

ANNUAL FREQUENCY DISTRIBUTIONS - STABILITY CLASS B   STATION =12842 TAMPA,FL   8OBS   1969-73

DIRECTION	SPEED(KTS) 0 - 3	4 - 6	7 - 10	11 - 16	17 - 21	GREATER THAN 21	TOTAL
N	0.000402	0.001644	0.001028	0.000000	0.000000	0.000000	0.003073
NNE	0.000333	0.001713	0.001028	0.000000	0.000000	0.000000	0.003073
NE	0.000324	0.001576	0.000891	0.000000	0.000000	0.000000	0.002790
ENE	0.000507	0.001028	0.001370	0.000000	0.000000	0.000000	0.002905
E	0.000722	0.002055	0.001850	0.000000	0.000000	0.000000	0.004626
ESE	0.001005	0.001918	0.001302	0.000000	0.000000	0.000000	0.004224
SE	0.000502	0.002055	0.001233	0.000000	0.000000	0.000000	0.003790
SSE	0.000502	0.002055	0.001439	0.000000	0.000000	0.000000	0.003996
S	0.000498	0.001987	0.001233	0.000000	0.000000	0.000000	0.003717
SSW	0.000315	0.001439	0.001781	0.000000	0.000000	0.000000	0.003535
SW	0.000242	0.001439	0.002329	0.000000	0.000000	0.000000	0.004010
WSW	0.000210	0.002055	0.003494	0.000000	0.000000	0.000000	0.005759
W	0.000603	0.003562	0.006028	0.000000	0.000000	0.000000	0.010193
WNW	0.000283	0.000959	0.000685	0.000000	0.000000	0.000000	0.001927
NW	0.000338	0.000685	0.000548	0.000000	0.000000	0.000000	0.001571
NNW	0.000269	0.000754	0.000685	0.000000	0.000000	0.000000	0.001708
TOTAL	0.007056	0.026921	0.026921	0.000000	0.000000	0.000000	

RELATIVE FREQUENCY OF OCCURRENCE OF B STABILITY = 0.060899

RELATIVE FREQUENCY OF CALMS DISTRIBUTED ABOVE WITH B STABILITY = 0.002124

Table A-8 (Continued).

ANNUAL FREQUENCY DISTRIBUTIONS - STABILITY CLASS A   STATION =12842 TAMPA,FL   8OBS   1969-73

DIRECTION	SPEED(KTS) 0 - 3	4 - 6	7 - 10	11 - 16	17 - 21	GREATER THAN 21	TOTAL
N	0.000046	0.000137	0.000000	0.000000	0.000000	0.000000	0.000183
NNE	0.000046	0.000137	0.000000	0.000000	0.000000	0.000000	0.000183
NE	0.000046	0.000137	0.000000	0.000000	0.000000	0.000000	0.000183
ENE	0.000023	0.000069	0.000000	0.000000	0.000000	0.000000	0.000091
E	0.000046	0.000137	0.000000	0.000000	0.000000	0.000000	0.000183
ESE	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
SE	0.000023	0.000069	0.000000	0.000000	0.000000	0.000000	0.000091
SSE	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
S	0.000114	0.000069	0.000000	0.000000	0.000000	0.000000	0.000183
SSW	0.000023	0.000069	0.000000	0.000000	0.000000	0.000000	0.000091
SW	0.000023	0.000069	0.000000	0.000000	0.000000	0.000000	0.000091
WSW	0.000069	0.000206	0.000000	0.000000	0.000000	0.000000	0.000274
W	0.000046	0.000137	0.000000	0.000000	0.000000	0.000000	0.000183
WNW	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
NW	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
NNW	0.000046	0.000137	0.000000	0.000000	0.000000	0.000000	0.000183
TOTAL	0.000548	0.001370	0.000000	0.000000	0.000000	0.000000	

RELATIVE FREQUENCY OF OCCURRENCE OF A STABILITY = 0.001918

RELATIVE FREQUENCY OF CALMS DISTRIBUTED ABOVE WITH A STABILITY = 0.000480

Table A-9. Population Distributions Around Plant Sites [A-13].

Plant	Population							
	0-1 km	1-3 km	3-5 km	5-10 km	10-15 km	15-20 km	Total 0-10 km	Total 0-20 km
FMC - ID	0	0	9,659	45,094	1,552	0	54,753	56,305
Monsanto - ID	0	1,075	3,223	694	0	1,463	4,992	6,455
Stauffer - MT	0	0	0	0	38,092	0	0	38,092
Stauffer - FL	551	4,007	17,892	62,204	36,812	8,394	84,654	129,860
Mobil - FL	0	1,388	1,568	7,628	20,483	32,019	10,584	63,086
Stauffer - TN	0	537	5,285	2,020	3,818	6,956	7,842	18,616
Monsanto - TN	0	0	1,011	17,175	13,531	10,637	18,186	42,354
Occidental - TN	412	337	19,659	9,450	5,084	6,700	29,858	41,642

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A-8 Regional Environmental - Energy Data Book, Southern Region, U.S. Dept. of Energy, Assistant Secretary for Environment, Office of Technology Impacts. DOE/TIC-10114/1, December 1978.

A-9 Seasonal and Annual Wind Distribution by Pasquill Stability Classes - U.S. Dept. of Commerce, NOAA Environmental Data Service, National Climatic Center, Federal Building, Asheville, N.C., Job No. 13365, March 22, 1972.

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A-11 Seasonal and Annual Wind Distribution by Pasquill Stability Classes - U.S. Dept. of Commerce, NOAA Environmental Data Service, National Climatic Center, Federal Building, Asheville, N.C., Job No. 13870, October 13, 1972.

A-12 Seasonal and Annual Wind Distribution by Pasquill Stability Classes - U.S. Dept. of Commerce, NOAA Environmental Data Service, National Climatic Center, Federal Building, Asheville, N.C., Job No. 15377, June 10, 1975.

A-13 Computer Code for Calculation of Population Distribution (based on 1980 U.S. Census Data, Science Applications, Inc.)

APPENDIX B - TYPICAL AIRBORNE EMISSION CONTROL EQUIPMENT

This appendix presents a more detailed discussion of some representative or common types of airborne emission control equipment used in the elemental phosphorus industry. Technical information and method of operation are discussed for each type of system considered.

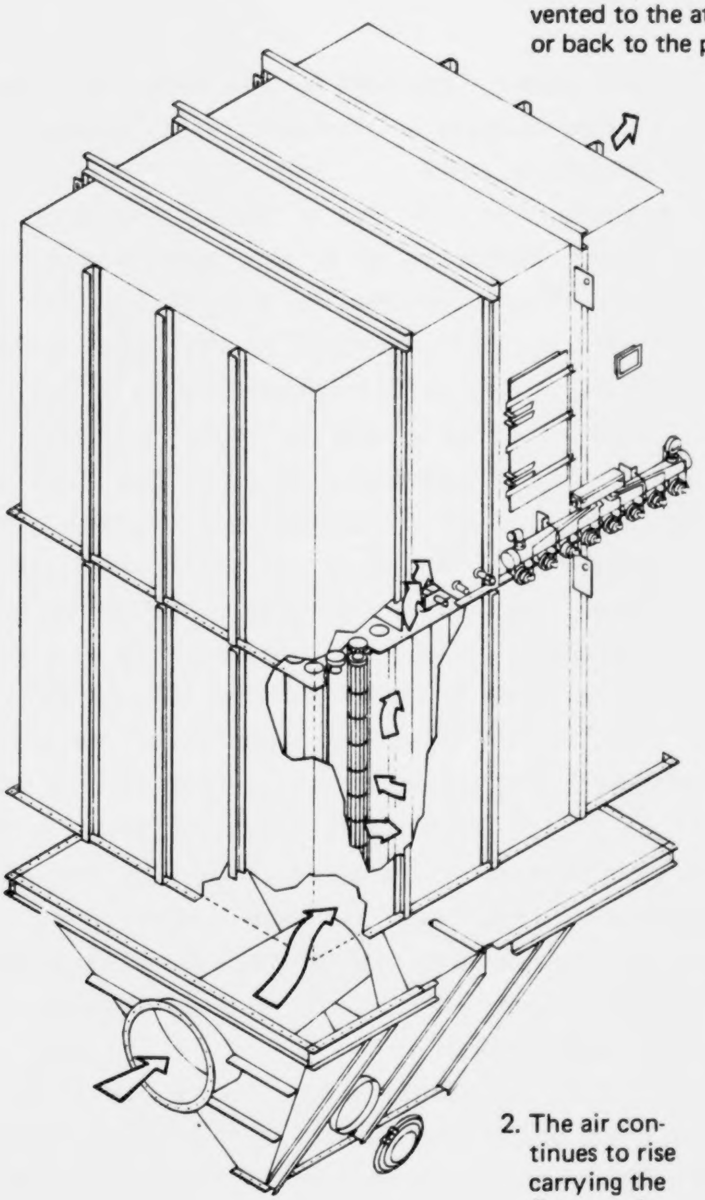
Two representative pulse-jet baghouse dust collectors are units manufactured by Flex-Kleen (Figures B-1 and B-2) and MikroPul (Figure B-3). The Flex-Kleen type unit operates as shown in Figure B-1; in this unit, heavier dust particles settle out and the finer dust is then collected on the outside of an array of filter bags. A pneumatic pulse-jet system (Figure B-2) provides continuous, automatic bag cleaning. On a timed cycle, a burst of compressed air is directed down through a venturi at the top of the bag. The air flow through the bag is momentarily stopped, and the bag is firmly flexed, causing the accumulated dust particles to drop off the bag into a silo or collector hopper. Since only one row of bags is cleaned at a time there is no interruption of air flow through the filter.

These type of units work equally well on both heavy and light dust loads. A relatively steady pressure drop across the collector makes a pulse-jet collector suitable for systems sensitive to changes in pressure drop. When maintenance is required, a top bag removal system allows a bag to be changed from the clear air side in 30 seconds. An adjustable timer maintains low pressure drop with minimum compressed air consumption. There are no moving internal parts, which reduces interior maintenance and minimizes system down time.

The Mikro-Pulsaire pulse-jet fabric collector (Figure B-3) consists of a group of filter bags enclosed in a metal housing. Dust-laden air is either forced or sucked into the collector housing through the hopper inlet in the storage-discharge hopper. Fine particles travel upward and are collected on the filter bags as with the Flex-Kleen system. The collector plenum houses the system blowtubes and supports for the solenoid valves. Clean air or gas is discharged through the exhaust outlet in the plenum. The housing contains the filter bag assemblies located above the hopper.

Operation

Method of operation is basically as follows:



1. Dust laden air slows down as it enters the collector. Heavier dust particles drop out.
2. The air continues to rise carrying the finer particles into the bag area.
3. As air passes through the bags, dust is captured and collected on the bag exterior.
4. The cleaned air passes up inside the bag into the clean air plenum then vented to the atmosphere or back to the process.

Figure B-1. Flex-Kleen Pulse-Jet Bag Collector.

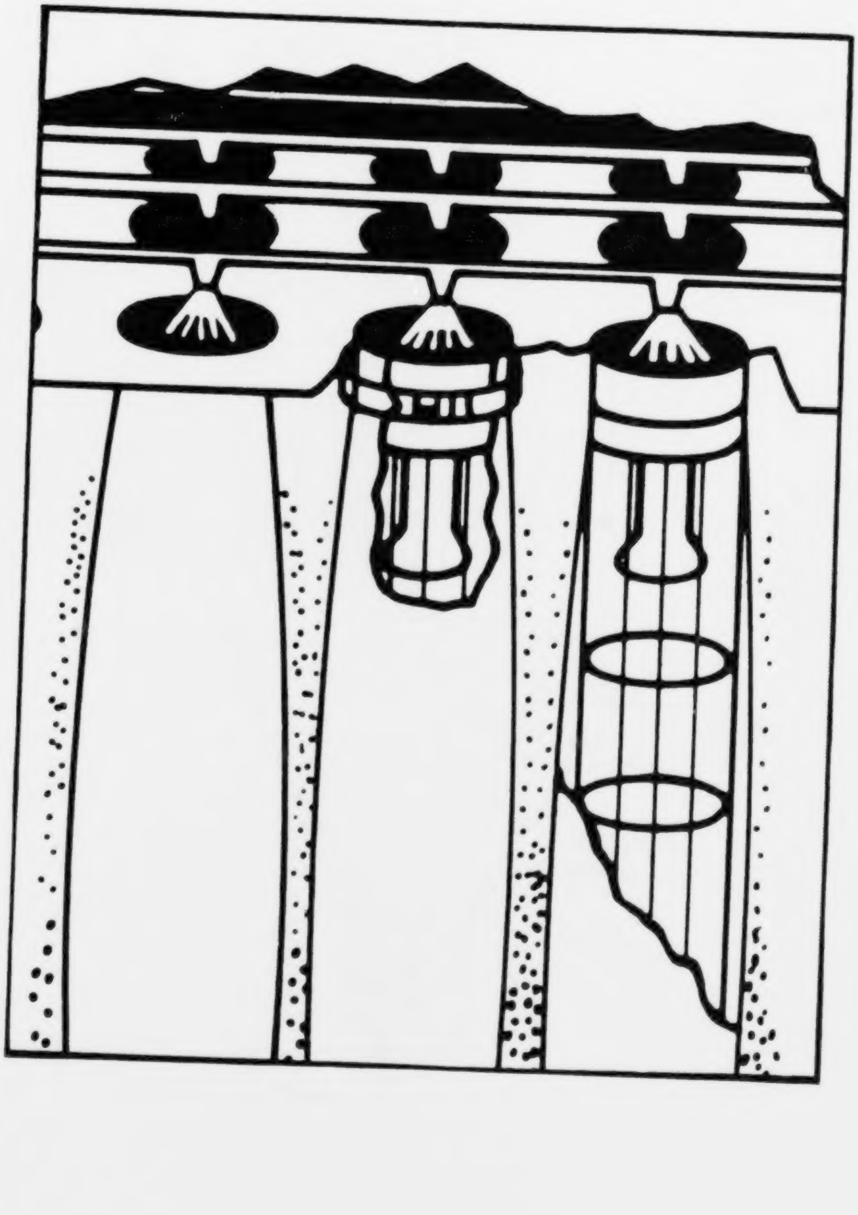


Figure B-2. Flex-Kleen Pulse-Jet Bag Cleaning.

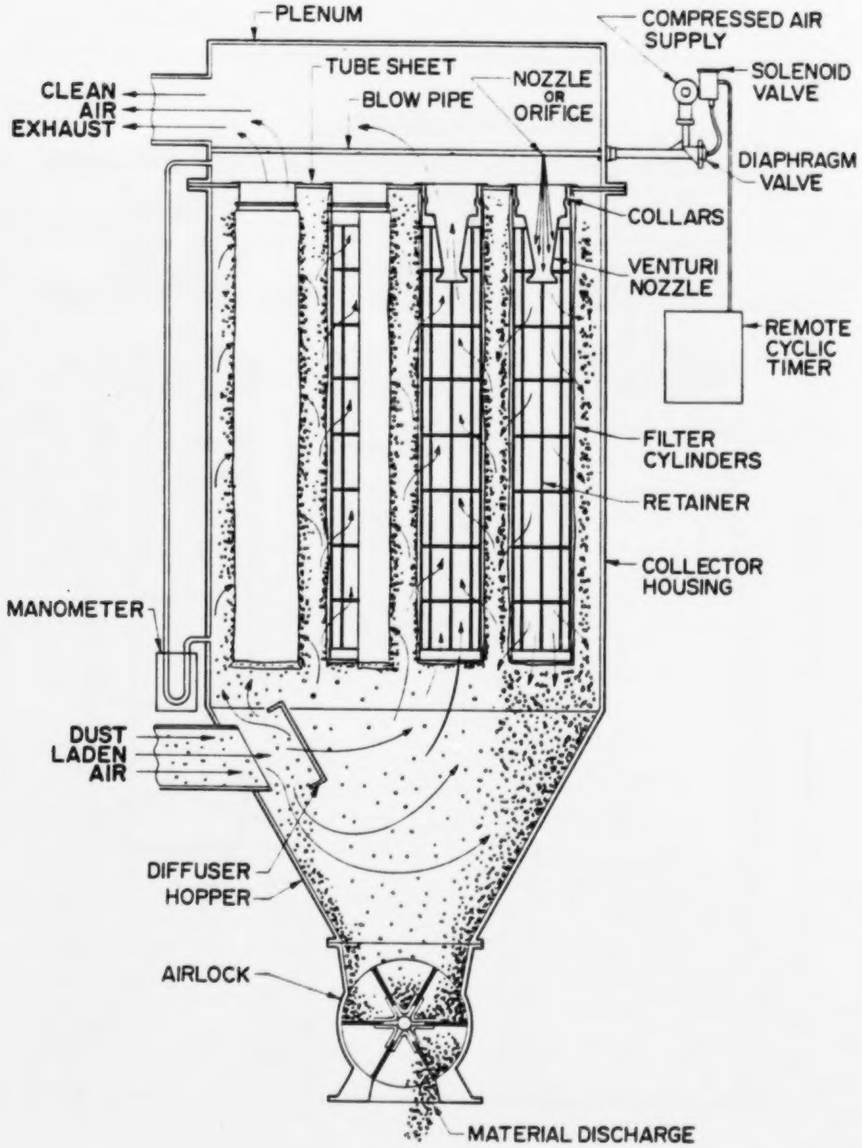

PLENUM
COMPRESSED AIR SUPPLY
TUBE SHEET
NOZZLE OR ORIFICE
SOLENOID VALVE
CLEAN AIR EXHAUST
BLOW PIPE
DIAPHRAGM VALVE
COLLARS
VENTURI NOZZLE
REMOTE CYCLIC TIMER
FILTER CYLINDERS
RETAINER
COLLECTOR HOUSING
MANOMETER
DUST LADEN AIR
DIFFUSER
HOPPER
AIRLOCK
MATERIAL DISCHARGE

Figure B-3. Mikro-Pulsaire Pulse-Jet Fabric Filter.

The hopper contains the inlet and a diffuser that absorbs the impact of the high-velocity dust particles and properly distributes the incoming gas. Pressure drop is indicated by a manometer connected at one end to the filter bag section and to the clean air plenum at the other end.

A signal from a remote cyclic timer opens a normally closed solenoid valve, which decreases the pressure in the tube connecting the solenoid to the right angle diaphragm valve causing the diaphragm valve to open. This permits a momentary jet of 100 psig air to flow from the air supply side to blowtube, down each venturi, and into each filter bag. All bags in a row are cleaned simultaneously. The unit operates with a relatively constant pressure drop and a collection efficiency of approximately 99.9 percent. Filter bags are typically 0.7 to 3.6 m long and 11.4 cm in diameter on 18 cm centers.

The most frequently used type of wet electrostatic precipitator is the Fluid-Ionic Hydro-Precipitrol system (Figure B-4). This unit consists of a series of concentric cylinders acting as collecting electrodes. Gas enters the unit at the bottom through a system of venturis and flows upward. A thin film of liquor flows down the cylinders from a pressurized distributing system. The result is a compact unit that allows efficient gas flow through a uniform electrical field. With this unit, particulates, aerosols, condensables, and gases (e.g., SO_2 and fluorides) can be collected.

When compared with a high-energy wet scrubber, the Hydro-Precipitrol uses relatively little power. It also is affected much less by the chemical and physical properties of the particles than a fabric filter. For instance, condensed fumes are removed by the Hydro-Precipitrol because its operating temperature always remains the same as the saturation temperature of the treated gas. While not affecting the Hydro-Precipitrol, high moisture content causes particles to become wet and blind the bag filter fabric.

The Hydro-Precipitrol has a maximum pressure drop of 5 cm (2 in) W. G. while attaining efficiencies comparable to conventional high-energy venturi scrubbers that have pressure drops of 100 to 150 cm (40 to 60 in) W. G. Because it has no internal moving parts, the Hydro-Precipitrol does not require much replacement or maintenance due to wear.

The most common type of wet centrifugal dust collector used in the elemental phosphorus industry is the American Air Filter Type R Rotoclone

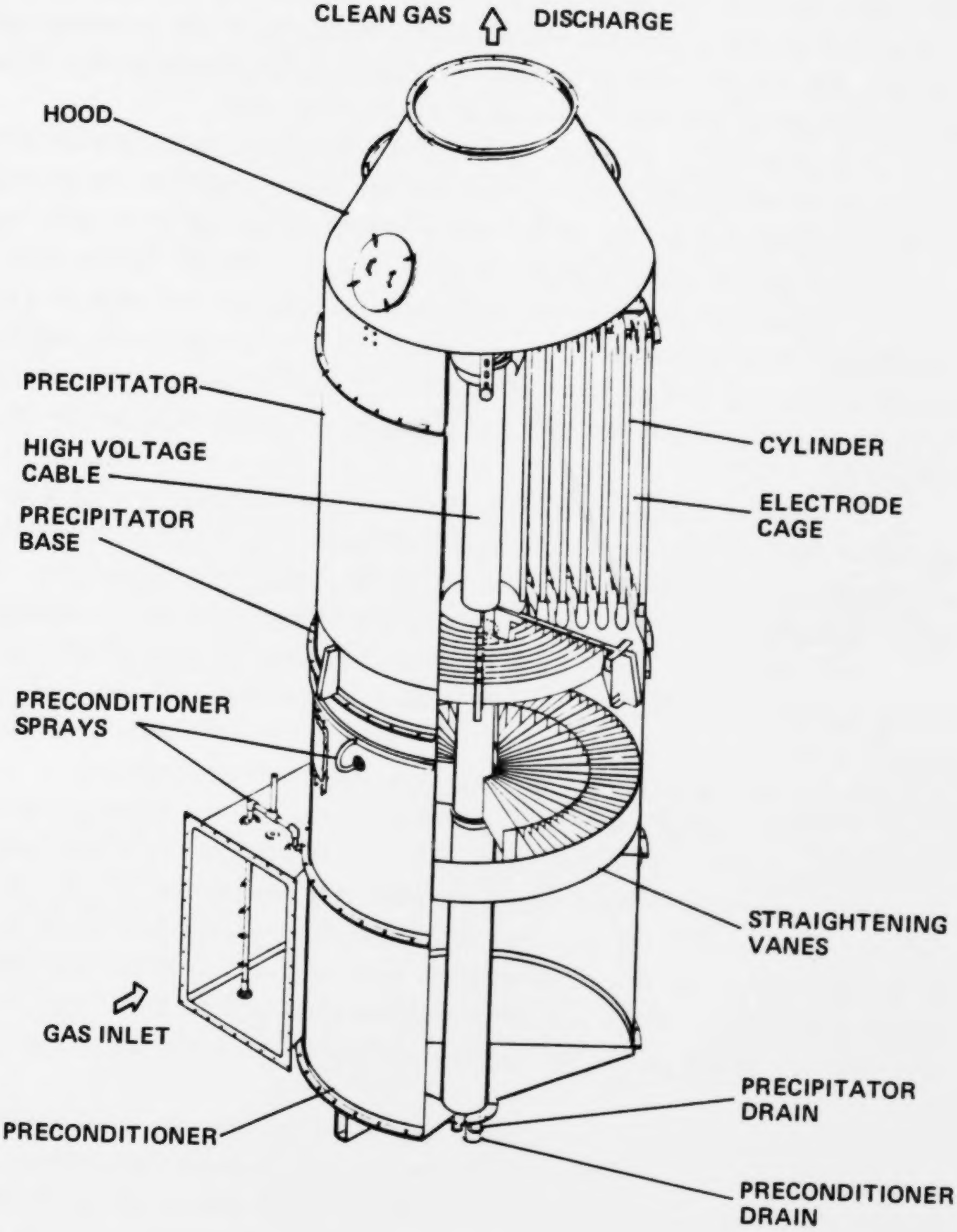

CLEAN GAS
DISCHARGE
HOOD
PRECIPITATOR
HIGH VOLTAGE CABLE
PRECIPITATOR BASE
PRECONDITIONER SPRAYS
GAS INLET
PRECONDITIONER
CYLINDER
ELECTRODE CAGE
STRAIGHTENING VANES
PRECIPITATOR DRAIN
PRECONDITIONER DRAIN

Figure B-4. Fluid-Ionic Hydro-Precipitrol Wet Electrostatic Precipitator.

(Figure B-5). This unit uses the well-established wet impingement principles as the collecting medium. The heart of the Type R Rotoclone is a series of specially designed double-inlet tubes. At 15 cm (6 in) W. G. collector resistance, each tube handles 127 CMM (4500 CFM) nominal rating. Resistance through the flow tubes varies proportionally to the gas flow. Each tube consists of three major parts: inlet cone, barrel and discharge cone. The tubes are placed in a three-compartment housing consisting of a collection section, water eliminator section, and clean air plenum.

Water introduced in each cone is carried to the periphery by high-velocity dust-laden gas entering the two tangential inlets of each cone. Dust particles impinge against the wetted peripheral surfaces. As the incoming air is spun down the inlet cone, the water and approximately 10 percent of the air is forced between the barrel and outlet cone. Clean air is passed through the center of the outlet cone, and the bleed-off air is passed through a vent tube and into the clean air plenum. Slurry from the Type R Rotoclone drains off continually from the water eliminator section. An emergency drain is provided in the clean air plenum to drain off any liquid from condensation or improper operation. Clean air passes through the clean air plenum to the atmosphere. The fan can either blow through or pull through this unit.

To ensure an uninterrupted flow, water is introduced by an open pipe at the inlet of each tube. In addition, supplementary water is added at the dirty air inlet to prevent buildup. Normal requirements for the Type R Rotoclone are 13 liters (3.5 gal) per 28.3 CMM (1000 CFM), excluding evaporation. Liquids other than water may be used in this unit. The Type R Rotoclone is available in standard sizes to 3060 CMM (108,000 CFM) and in larger sizes upon request. Its design saves approximately 50 percent of the floor space required for a conventional wet scrubber.

A relatively new type of wet filtration system is the Andersen-2000 "CHEAF" Cleanable Media High Efficiency air filter (Figure B-6). This unit combines the best features of filtration equipment, wet scrubbers, and Brownian Motion or diffusion-controlled mist eliminators. It is mechanically simple, inherently reliable, and physically small when compared with other fine particle airborne emission control equipment. Two different CHEAF systems are available: the continuously cleaned CHEAF and the renewable media CHEAF. The renewable media unit is used when both water soluble

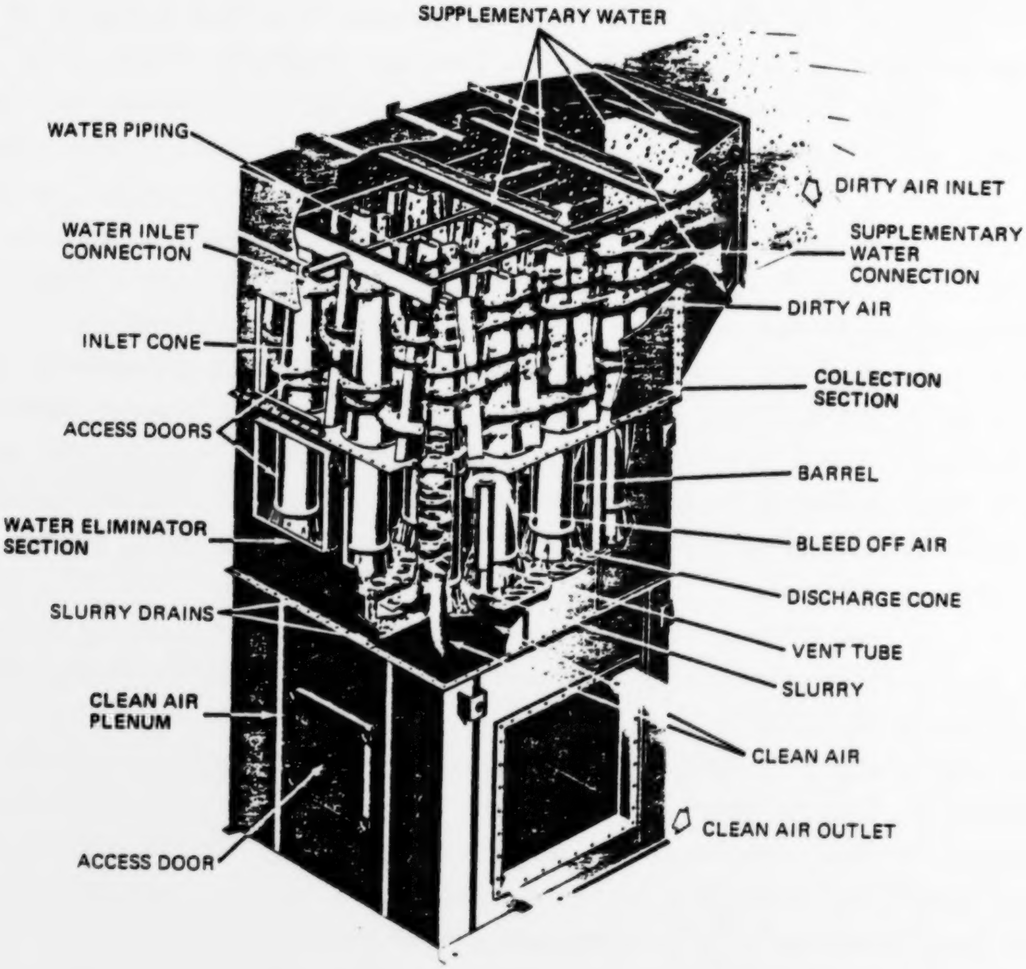

SUPPLEMENTARY WATER
WATER PIPING
DIRTY AIR INLET
WATER INLET CONNECTION
SUPPLEMENTARY WATER CONNECTION
DIRTY AIR
INLET CONE
COLLECTION SECTION
ACCESS DOORS
BARREL
WATER ELIMINATOR SECTION
BLEED OFF AIR
DISCHARGE CONE
SLURRY DRAINS
VENT TUBE
SLURRY
CLEAN AIR PLENUM
CLEAN AIR
CLEAN AIR OUTLET
ACCESS DOOR

Figure B-5. American Air Filter Type R Rotoclone Wet Centrifugal Dust Collector.

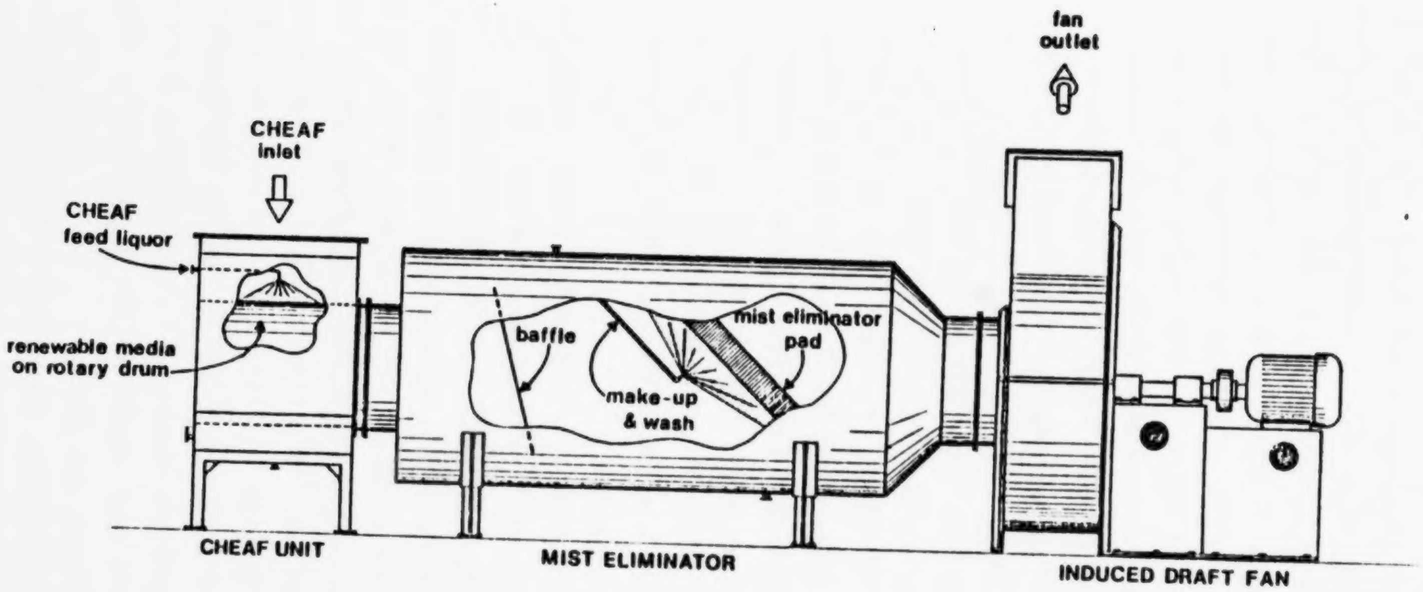

fan outlet
CHEAF inlet
CHEAF feed liquor
renewable media on rotary drum
baffle
make-up & wash
mist eliminator pad
CHEAF UNIT
MIST ELIMINATOR
INDUCED DRAFT FAN

Figure B-6. Andersen-2000 "CHEAF" Cleanable Media High Efficiency Air Filter.

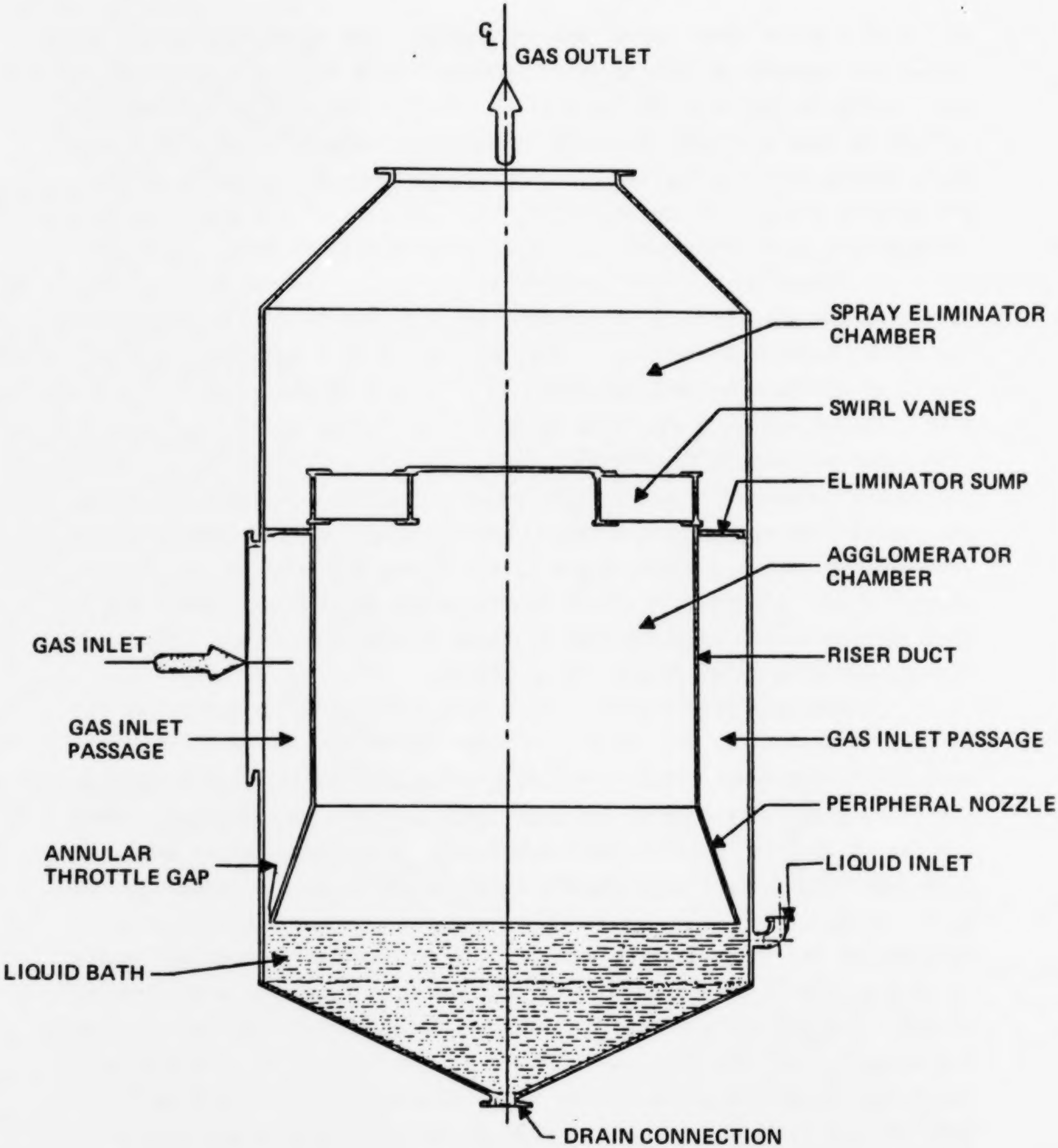
and water insoluble particulate matter are to be removed from acidic or strongly basic gas streams.

A 3-cm thick fiber glass filtration mat is normally used as the filter medium on the renewable media CHEAF. The filter is installed over a perforated filtration drum and is irrigated with a recirculated scrubbing solution. The system is typically operated with a filter face velocity of about 490 m/min (1600 ft/min) and at a differential pressure of between 50 and 90 cm (20-35 in) W. G. The mist separation section usually requires an additional 3.8 cm (1.5 in) W. G. The water soluble particulate matter is collected on the filter mat and is then washed through with the scrubbing liquid introduced from spray nozzles mounted around the filtration drum. The insoluble particulate matter is retained in the filter, and as the concentration in the filter mat builds to where excessive differential pressure would degrade flow, the filter mat is automatically advanced in small increments to expose fresh filter media to the gas stream.

The cost of the filter media consumed plus electrical power for the induced draft fan normally results in a substantially lower operating cost than for a comparable performance scrubbing system. It has substantially lower differential pressures and lower liquid bleed rates than venturi scrubbing systems. Capital costs are about the same as those for a venturi scrubber system but are substantially lower than those for a wet electrostatic precipitator system.

There are many types of wet scrubbers used for airborne emission control in the elemental phosphorus industry. One type frequently used is the Western Precipitation Type D Turbulaire scrubber (Figure B-7), which is used where dust particle sizing and process conditions require low energy inputs (pressure drops <35 cm (14 in) W. G.). These energy requirements are below the range in which the collecting mechanisms of conventional venturi scrubbers begin to take full effect. This unit has a vertical flow design, which requires a minimum of floor space. A peripheral gas nozzle combines a low-energy venturi effect with collection by impingement on the liquid bath. To accommodate changes in process conditions or more stringent emission codes, the pressure drop can be varied by means of a simple internal adjustment of the peripheral gas nozzle.

Slurries are kept suspended in the sump by the action of the gases being scrubbed. Mist elimination is accomplished with the centrifugal



℄
GAS OUTLET
SPRAY ELIMINATOR CHAMBER
SWIRL VANES
ELIMINATOR SUMP
AGGLOMERATOR CHAMBER
GAS INLET
RISER DUCT
GAS INLET PASSAGE
GAS INLET PASSAGE
PERIPHERAL NOZZLE
ANNULAR THROTTLE GAP
LIQUID INLET
LIQUID BATH
DRAIN CONNECTION

Figure B-7. Western Precipitation Type D Turbulaire Wet Scrubber.

action of a set of swirl vanes, and the droplets once separated from the gas stream are returned by gravity into the sump. Water needs are minimized by the ability to recirculate the heavily concentrated slurries often containing as much as 5 percent solids by weight. These units have no moving parts and do not plug easily. Particulate removal efficiencies for particles 1 μm and 5 μm in diameter are approximately 97 and 99.88 percent, respectively, with a pressure drop of 35-40 cm (14-16 in) W. G.

Another type of wet scrubber is the Ducon Type VVO Oriclone venturi scrubber (Figure B-8). This unit is a high-energy dust and fume collector designed to bring dust-laden gas into contact with the scrubbing liquid by acceleration and turbulence in a venturi throat. Dust-laden gas enters the wet-approach gas inlet at top center, while scrubbing liquid is introduced on the wall through open pipes. The gas and scrubbing liquid are thoroughly intermixed in the venturi throat. The gas with entrained solids and liquid then passes into a centrifugal separator where scrubbing liquid and collected solids flow downward to the slurry discharge or an integral recycle tank. Cleaned gas exits through a top gas outlet. There are no spray nozzles or distribution jets in which solids can collect. Thus, any slurry capable of being pumped can be handled.

When a predetermined pressure drop level must be maintained for varying inlet volumes, the Type VVO scrubber can be provided with an adjustable throat mechanism. Thus, pressure drop can also be adjusted to upgrade collection efficiency to meet increased process or code requirements. There are two adjustable throat designs available. One uses a center moveable blade and is similar to the butterfly damper commonly used in exhaust system ducts, with a flat plate fixed to a rotating shaft. The other design consists of two side moveable plates or blades mounted on parallel shafts located on each of the long sides of, and at the entrance to, a rectangular throat. The throat area can be decreased by shaft rotations so that the blade edges move from the sidewalls toward the centerline of the throat. The volume capability of the system ranges from 5 to 2000 CMM (200 to 70,000 CFM) for standard equipment with higher volume possible with multiple units or special design considerations. Design pressure drop is 20 to 152 cm (8 to 60 in) W. G. or higher with normal venturi liquid requirements of 30 to 45 liters (8 to 12 gal) per 28.3 CMM (1000 CFM). Efficiency can be varied up to 99.9 percent, depending on pressure drop.

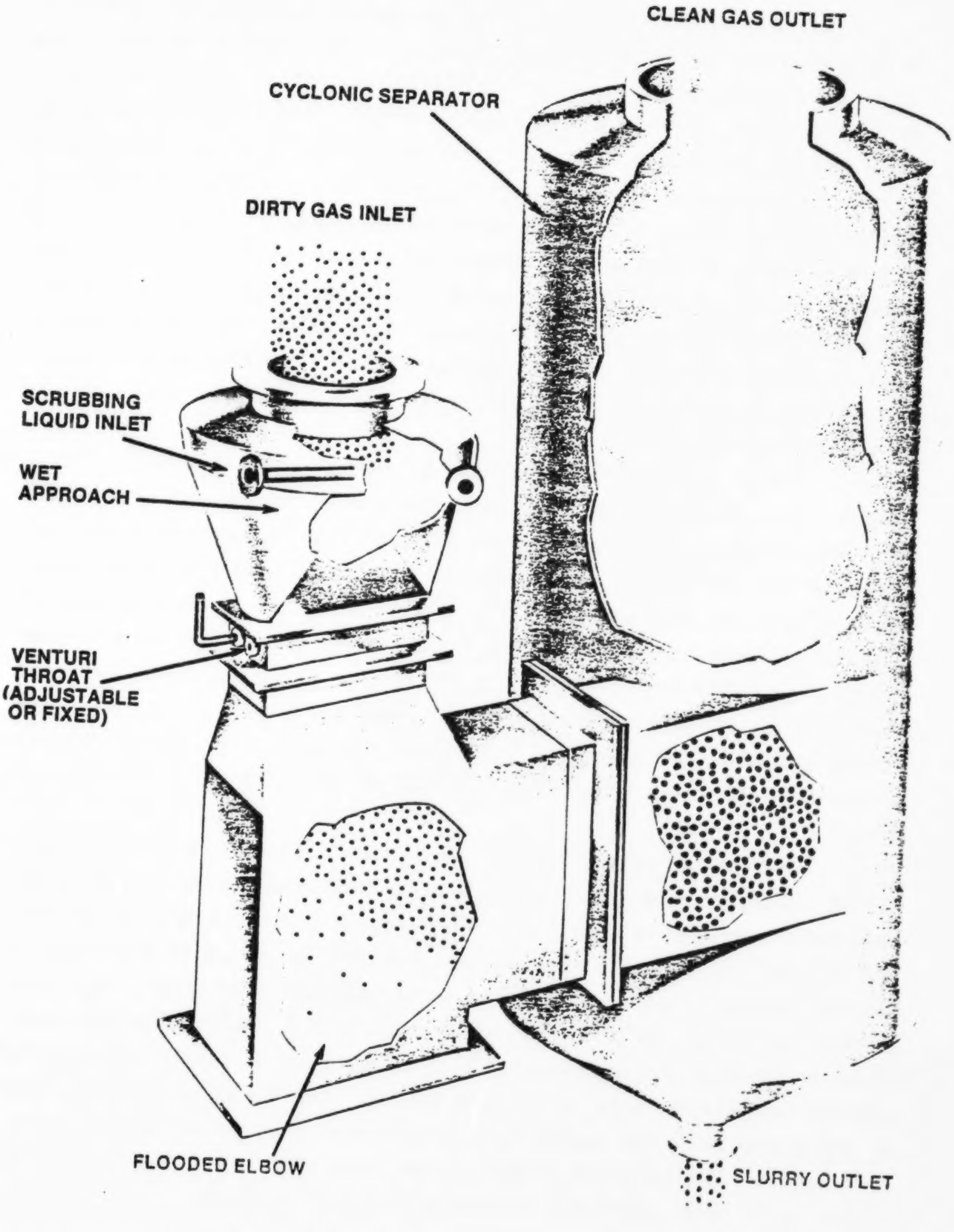

CLEAN GAS OUTLET
CYCLONIC SEPARATOR
DIRTY GAS INLET
SCRUBBING LIQUID INLET
WET APPROACH
VENTURI THROAT (ADJUSTABLE OR FIXED)
FLOODED ELBOW
SLURRY OUTLET

Figure B-8. Ducon Oriclone Type VVO Venturi Scrubber.

The American Air Filter Kinpactor venturi-type scrubber (Figure B-9) is similar to the Ducon Type VVO scrubber. The contaminated gas stream is accelerated through a venturi-shaped throat section reaching extremely high velocities. Water introduced ahead of the throat is atomized by the high-velocity gas stream, and dust particles collide with and are captured in the small droplets. In the long diverging section behind the Kinpactor throat, static pressure is regained as the velocity of the gas stream is reduced. Submicron size particulate and water droplets coalesce during this interval providing additional collection. The water-laden gas stream enters the cyclonic separator (Figure B-10) tangentially where droplets are removed by centrifugal force and impingement. Clean, droplet-free air passes through the separator outlet and slurry is continuously drained from the water eliminator section.

Water is injected in the form of sheets rather than solid jets or sprays. This sheet is introduced under pressure to achieve optimum trajectory and throat coverage. There are no void areas through which the contaminated gas can bypass. Water requirements range from 22.5 to 45 liters (6 to 12 gal) per 28.3 m^3 (1000 ft^3) of gas. Water can be recirculated if evaporation losses are replaced. The recirculation system must contain some means of clarification or at least be designed to limit the concentration of suspended solids. Normal pressure requirement is 40 psig at the Kinpactor supply manifold. Efficiency of 99.5 percent for submicron particulates can be achieved with approximately 100 to 127 cm (40 to 50 in) W. G. pressure drops.

One type of mist eliminator used in the elemental phosphorus industry is a Clermont fine-fiber, thick-bed, candle-filter system (Figure B-11). This system contains a number of aerosol candle filters capable of collecting 99.5 percent of all liquid and solid particles <3 μm in diameter. A typical system consists of candles supported on a tube sheet. Gas flow through the filter may be inside-out or the reverse. The candles are self-draining, in that the agglomerated liquids drain to the candle tank sump in equilibrium with the inlet gas liquid loading. Soluble solids are dissolved by irrigating with the appropriate dissolving medium and collected in the tank sump. A nonirrigated filter system, used when all pollutants are in liquid mist form, does not require a circulating fluid.

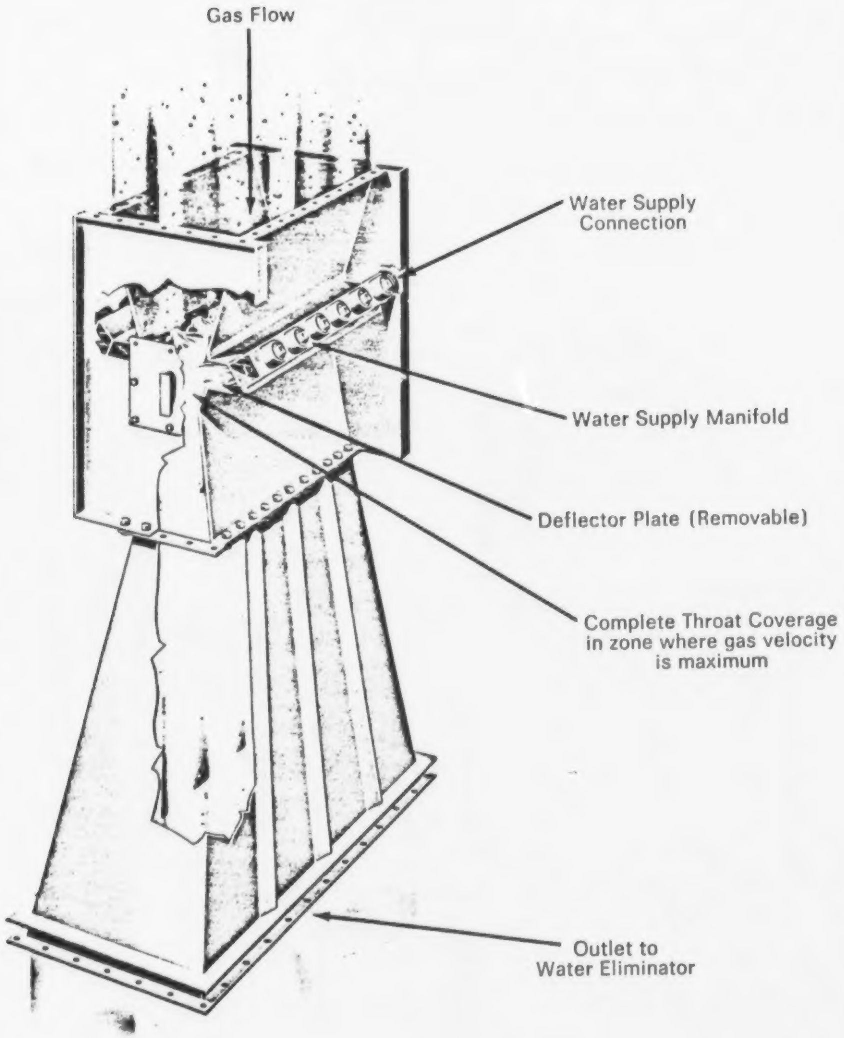

Gas Flow
Water Supply Connection
Water Supply Manifold
Deflector Plate (Removable)
Complete Throat Coverage in zone where gas velocity is maximum
Outlet to Water Eliminator

Figure B-9. American Air Filter Kinpactor Venturi Scrubber.

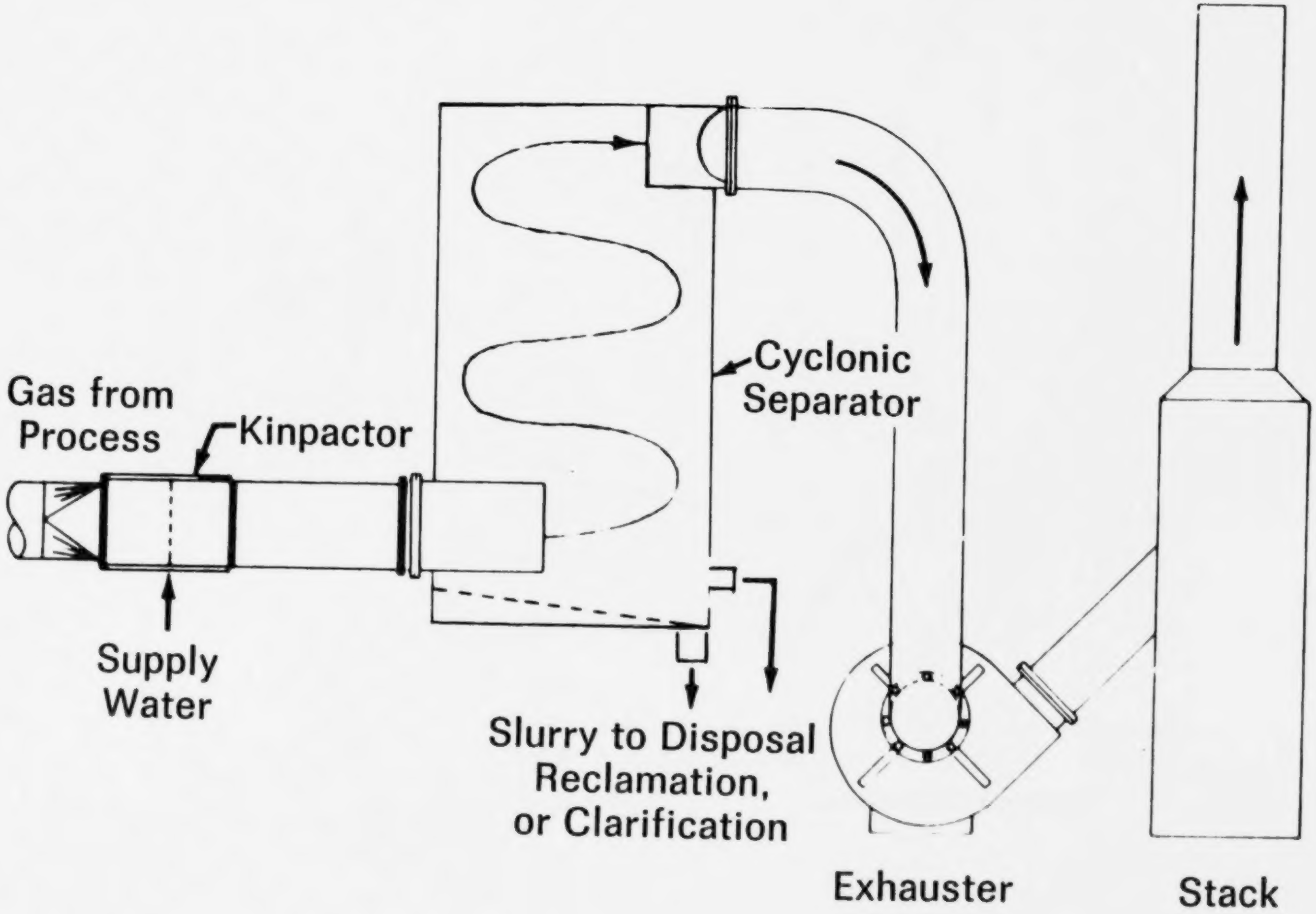

Gas from
Process
Kinpactor
Supply
Water
Cyclonic
Separator
Slurry to Disposal
Reclamation,
or Clarification
Exhauster
Stack

Figure B-10. Typical Arrangement of AAF Kinpactor With Cyclonic Separator.

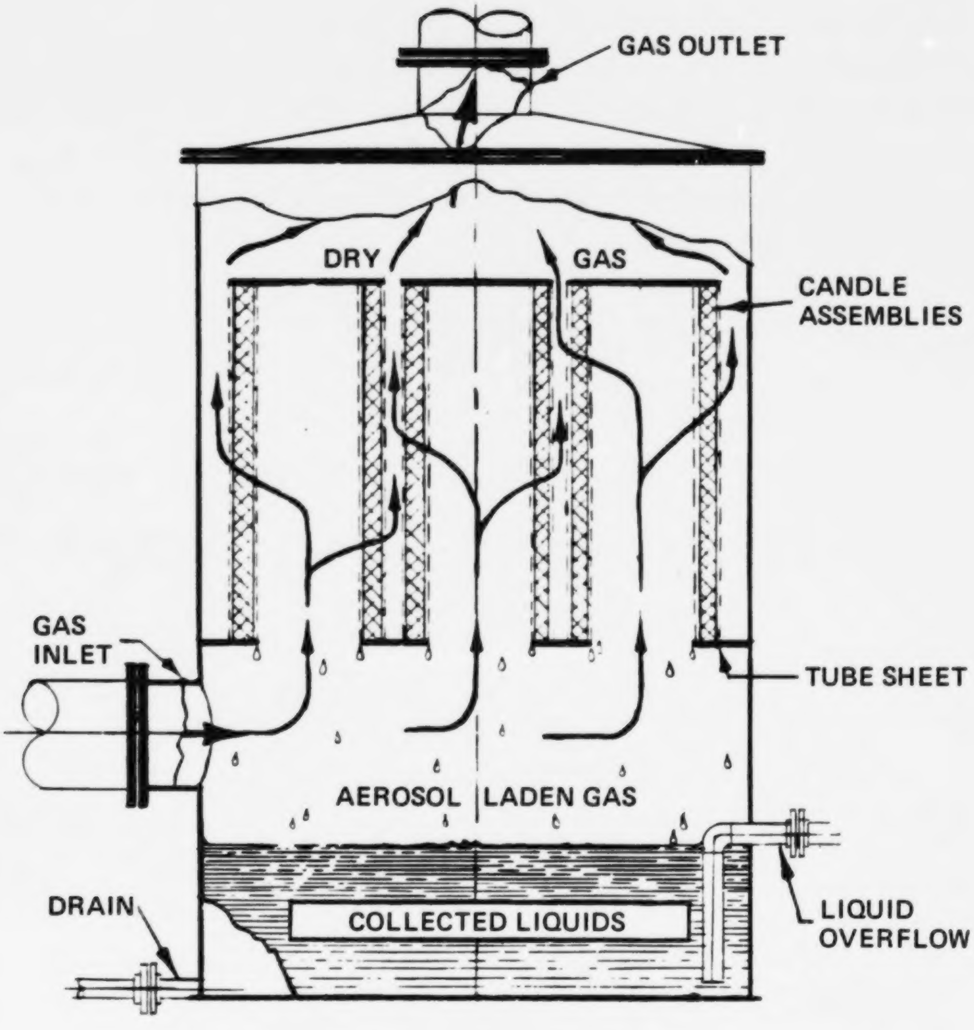

GAS OUTLET
DRY GAS
CANDLE ASSEMBLIES
GAS INLET
TUBE SHEET
AEROSOL LADEN GAS
DRAIN
COLLECTED LIQUIDS
LIQUID OVERFLOW

Figure B-11. Flow Design of Clermont Aerosol Candle Filters.

The design velocity across the face of the filters is approximately 9 m/min (30 ft/min), and an increase of up to 30 percent has very little effect on the efficiency. The pressure drop will, however, increase in an approximately linear relationship to gas flow or velocity. Reducing gas velocity will have the same effect on pressure drop but will increase efficiency. Typical pressure drops across the candles are 18 to 25 cm (7 to 10 in) W. G. for a nonirrigated system and 30 to 38 cm (12 to 15 in.) W. G. for an irrigated system. Candles are 40.6 cm (16 in) or 70 cm (24 in) in diameter with capacities of 26.6 ACMM (940 ACFM) and 44.5 ACMM (1570 ACFM), respectively. To prevent re-entrainment of condensed liquid mist, exhaust velocity on the downstream side of the filter elements should be a maximum of 365 m/min (1200 ft/min).